SunSpot: A Spatial Decision Support Web-Application for Exploring Urban Solar Energy Potential

by

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AUTHOR'S DECLARATION

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Abstract

The growing necessity for meaningful climate change response has encouraged the development of global warming mitigation and adaptation initiatives. Urban solar energy generation is one opportunity that has been investigated by numerous cities through various solar potential Web-applications. However, as solar feasibility can vary considerably across a small geographic area due to variations in local topography and feature shading, there is no one-size-fits-all solution to be implemented.

This thesis investigates how a Web-based spatial decision support system (SDSS) can enable non-experts to explore urban solar feasibility and, to a lesser extent, issues related to urban heat. First, a conceptual framework is developed that investigates the linkages between SDSS, Web technologies, public participation, volunteered geographic information, and existing green energy initiatives. This framework identifies the relevance between these fields of study as well as a number of opportunities for improving on past work and taking advantage of new technical capabilities. Second, in order to test the opportunities identified, SunSpot was developed. This Web-SDSS investigates rooftop solar feasibility as well as land cover and surface temperature dynamics relating to the urban heat-island effect in Toronto, Ontario, Canada. A number of solar resource datasets were developed in order to facilitate the decision making capabilities of SunSpot. This was done using a combination of different topographical data sources, atmospheric data, and a raster-based irradiance model called Solar Analyst. Third, a number of in-person workshops were conducted to obtain feedback on SunSpot's usability and ability for users to understand the visual layers and results. Finally, this feedback was analyzed to identify the successes and challenges of SunSpot's capabilities and design. This revealed a number of recommendations for further development of SunSpot, as well as opportunities for future research relating to the development of local scale solar resource data and the development of similar Web-SDSS applications.

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For Mom.

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Chapter 1 – Introduction

1.1 Problem Statement

Spatial decision making has traditionally been the domain of policy makers, planners, and other specialists who possess the knowledge and technical skills required to develop and execute Geographical Information Systems (GIS) and related technologies. These technologies are seeing adaptation for use in increasing public involvement and collaboration among larger groups of decision makers. While these opportunities serve to improve decision making capabilities, they also possess new challenges in making advanced tools and methodologies accessible to less specialised audiences.

Spatial decision support forms the bridge between the analytical capabilities of a traditional GIS and the dynamic nature of the data and knowledge brought forth by the decision makers. By design, a spatial decision support system (SDSS) aims to provide the user with customised tools required for the decision making process of the specific issue being investigated. By involving the user in the process, *a priori* knowledge can be obtained from the user and leveraged as a data source, improving the accuracy and usefulness of the results (Densham, 1991).

Evolution in the capabilities of Web-GIS lends itself to the paradigm of spatial decision support through reaching larger audiences with greater ease, bi-directional data transfer, customisable interface design, and the ability to create and present results in the form of interactive media. The combination of this and SDSS, known as Web-SDSS, serves to make decision support processes accessible to larger audiences including those who are not considered traditional decision makers (Kingston et al., 2000). While these individuals may possess unique knowledge or hold stake in the issues being investigated, their experience with SDSS may be limited. Engaging these users requires careful consideration of the challenges involved, leading to the construction of SDSS in a manner that leverages computational ability with human expertise and knowledge of one's domain.

This thesis presents a Web-SDSS designed to investigate possible courses of action for implementing aspects of a number of environmental initiatives in Toronto, Ontario. This focuses on urban green energy generation in the form of roof-based solar technology and, to a lesser extent investigates the urban heat-island (UHI) effect and its relationship with land cover and surface temperature. UHI is the phenomenon seen in dense, urban areas where land cover change affects air temperature, and is one of a number of local-scale factors stressed by climate change (Karl and Jones, 1989) Through this investigation, it explores how the design of Web-SDSS affects the audience's understanding of presented data and their ability to make informed decisions using decision support methodologies.

1.2 Context

The overwhelming evidence for anthropogenic climate change has spurred the need to combat global warming through mitigation and adaptation actions found across all industries and at all levels of government (Rabe, 2007; Burke and Ferguson, 2010). Of particular interest in many Western nations are opportunities at the local scale, which exist to improve public interest and participation. This is accomplished through the development of climate change policy and programs that enable individuals to become engaged in emissions reduction projects (Bushnell et al., 2008; Zimmerman and Faris, 2011).

One of these policy initiatives is Ontario's Green Energy Act, passed in 2009 with the goal of increasing renewable energy production as well as promoting growth of the renewable energy industry in the province. The Act permits individuals and small-scale private organizations to connect green energy sources to the local power grid and receive financial incentives in the form of feed-in-tariffs (FIT). In conjunction with this Act, the Ontario Power Authority started the FIT and MicroFIT (for small-scale projects) programs in 2009 as a way to encourage adoption of green energy generation technologies at small and medium scales. As of August 7, 2012 there were over 10 000 applications submitted for approval to these programs, showing a great deal of public interest and initial success in the strategy (OPA, 2012a). However, the steep financial risk associated with these opportunities can deter potential participants from joining the program without being able to effectively determine their individual feasibility. This is because opportunities such as roof-mounted solar panels can vary considerably across space in an urban setting. Factors such as roof aspect, slope, and nearby shading must be accounted for when determining feasibility.

Other initiatives aim to encourage the adoption of mitigation and adaptation opportunities at a number of different scales at the city level. Some of these include the increase in tree canopy coverage in response to UHI, managing stormwater runoff, encouraging the construction of environmentally friendly buildings, and the implementation of energy efficient government and public transportation fleets. In Toronto, one example is the Green Development Standard (GDS) that has a set of mandatory and optional environmental requirements for all new developments in the city. This includes measures for green energy, tree canopy cover and other 'green' land use, stormwater runoff, and energy efficiency (City of Toronto, 2010). Many of these factors are not isotropic and Web-GIS tools can help investigate how they might be suitable across an area.

Communicating the opportunities available through these programs is no simple task as the audience varies in technical capabilities and their understanding of the underlying issues. Web-SDSS is an ideal method for this as each factor is spatial and calculating feasibility requires information that is often privy to the individual. The use of Web-SDSS in the context of investigating climate change mitigation and adaptation opportunities at the local scale is not new. Dean et al. (2009) investigated a handful of Web-SDSS tools developed in the United States to support the decision-making process of individuals investigating photovoltaic potential. While the audience does not exclude traditional expert decision makers, the tools were typically designed to be accessible to individuals of any expertise-level.

From the investigation of these and other green energy Web-SDSS tools, opportunities were identified for improving the techniques previously employed. Improved topographic data allows for the modeling of more detailed solar resource data, which requires fewer assumptions to be made and less information required from the user to estimate feasibility. Greater care in development of the Web interface by considering the target audience's needs can permit the application to be intuitive while providing increased capabilities to aid in investigating the data and the decision making process.

For this thesis, a new Web-SDSS tool called *SunSpot* was designed and created. *SunSpot* makes a number of data sources and tools available to investigate a number of small scale adaptation and mitigation projects available at the local level. These include investigating photovoltaic (PV) feasibility for urban rooftops, and exploring issues relating to the urban heat-island effect, tree canopy cover, storm water management, and other issues relating to the Toronto Green Standard. In addition, methods for producing the requisite datasets are described, with a focus on the ease in which the data can be reproduced for other study areas.

1.3 Research Objectives

This thesis has four objectives:

1. Development of a literature review that identifies the intersection between climate change policy, Web-SDSS and related technologies, and the growing social involvement related to climate change issues at the local level, with an emphasis on assessing rooftop solar panel installations.
2. Design and build the Web-SDSS known as SunSpot and produce the data necessary to power the investigatory and decision making capabilities of the Web application.
3. Test SunSpot's effectiveness in communicating local level climate change issues and provision of decision making tools that are usable by all intended parties.
4. Provide recommendations for the future development of similar Web-SDSS based on issues and opportunities identified through the development and testing of SunSpot.

1.4 Organisation of Thesis

This thesis is structured in the following order. Chapter Two presents a literature review that investigates the policy, social, and technological issues relating to climate change at the urban scale with specific focus on Toronto, Ontario. Through this, a conceptual framework is developed that identifies opportunities found at the intersection of these fields of study. This framework provides the rationale for choices made in SunSpot's development. Furthermore, literature on solar modeling approaches is investigated to identify the ideal methods for generating solar resource data. Existing Web applications and tools that have been developed to assess solar feasibility are also investigated. Chapter Three investigates the methodology behind developing solar resource data and the topographic data development methods required by ESRI Solar Analyst. It then details the process undertaken for generating solar resource data for the identified case study of Toronto, Ontario. The design of each component of SunSpot is described along with the rationale behind the choices made. Chapter Four discusses the research study designed to test the effectiveness of the design choices behind SunSpot's interface and functionality. This is done by having individuals follow a script to use the application and respond to a number of open and closed-ended questions. Chapter Five presents the results of this research study and discusses their meaning in relation to the research challenges identified in Chapter Two. Chapter Six concludes by summarising the outcome of this research and introduces a number of potential future areas of research.

Chapter 2 – Literature Review

This chapter develops a framework that shows the significance and relationship of the fields of research related to this study. Section 2.1 identifies trends in the effectiveness of climate change policy at different levels of government, and in particular the contrast between 'top-down' and 'bottom-up' approaches. Section 2.2 describes how geographical information systems (GIS) are being used to include the public in policy development. Section 2.3 investigates how Web-GIS technologies provide opportunities for improving communication between policymakers and the public. The role played by of Web-based decision support and public participation GIS technologies and methods is investigated. Section 2.4 investigates common approaches for developing solar energy datasets for Web-based decision support tools. This creates a foundation for the discussion on the approach taken in Chapter 3. Section 2.5 discusses the relationships between the fields of study and identifies a number of opportunities for improving previous approaches taken in developing these tools. Section 2.6 summarises what has been achieved in this literature review and introduces the objective of the next chapter.

2.1 Climate Change Policy

It has been well established by numerous scientific bodies worldwide that anthropogenic climate change has potential significant impacts on numerous natural and human systems (IPCC, 2007). While climate change as an internationally recognised issue dates back to the first World Climate Conference in Geneva, Switzerland in 1979, it was not until the 1990s for action to take place (Shogren and Toman, 2000). This occurred in the form of an intergovernmental panel of experts who worked to define the problem in detail and identify a course of action to be taken. In the case of the Kyoto Protocol in 1992, goals for each ratified nation were formed (UNFCCC, 1998). The responsibility of meeting these goals falls on each nation where federal as well as state and provincial policy shapes potential courses of action, typically in a broad manner including regulatory actions such as 'cap-and-trade' programs and broad action over energy and land use policy (Burke and Ferguson, 2010).

There is debate on the efficacy of this ‘top-down’ methodology as the Kyoto Protocol is argued to have failed to cause meaningful change in national greenhouse gas (GHG) emissions (Kellow, 2009; Prins et al., 2010). In the discussion of potential alternatives, some authors identify the importance of ‘bottom-up’ policy that places an emphasis on local governments to take action (Rabe, 2007; Selin and VenDeever, 2007; Lutsey, 2008; Rabe, 2008). This is due to a number of unique opportunities that lower levels of government have that relate to issues on climate change adaptation and mitigation. Some of these include energy generation, efficiency, and use, transportation policy and infrastructure, land use policy, and greater political freedom to act (Zimmerman and Faris, 2011).

This section presents trends identified in literature on climate policy at the international level as well as within Canada and the United States. Arguments are made for the efficacy of policy development by lower levels of government to generate meaningful action. This so-called ‘bottom-up’ approach is argued to be effective for many reasons, including the opportunities it provides for the public to become engaged in mitigation and adaptation initiatives. Of particular focus are the Ontario Green Energy Act and the Toronto Green Development Standard, both of which exemplify opportunities for action by individuals and decision makers at the local level.

2.1.1 International Top-down Policy

Identifying and responding to the issues related to climate change have been seen as an international effort. GHG emissions including carbon dioxide and methane are emitted by all nations to varying extents. Countries that contribute the most initially included those in North America and Europe, but growing fossil fuel consumption in countries like China and India greatly expand the scope of the problem. GHG emissions cannot be isolated or moved like other sources of waste, and ultimately spread through the atmosphere, having an impact on all nations (Rabe, 2007; Lutsey and Sperling, 2008). This is identified as a ‘global commons’ problem, referring to how the impacts are seen worldwide, despite there being identifiable sources (Burke and Ferguson, 2010).

As a global response to this problem, the United Nations Framework Convention on Climate Change (UNFCCC) was formed in 1992. The international treaty identified the problem of climate change and formed a framework regarding the need to reduce GHG emissions through levels of responsibility based on wealth and ability (Shogren and Toman, 2000). The Kyoto Protocol was developed from this framework in 1997, formalising GHG emission reduction goals as a percentage below 1990 levels for each country to reach by the end of 2008 to 2012 (UNFCCC, 1998). By signing and ratifying the Kyoto Protocol, a nation became responsible for reducing GHG emissions by a negotiated amount. Failing to meet benchmarks and ultimately the goal by the deadline could potentially result in sharp financial penalties. The Kyoto Protocol was also designed to provide flexibility on how nations reached these goals (Shogren and Toman, 2000). These included the ability to trade emissions reduction requirements (also known as 'cap-and-trade'), the opportunity to set up reduction projects in developing nations, and the ability to co-operate with other nations in joint projects.

Literature discussing the progress and results of the Kyoto Protocol has been largely negative as many argue that it has failed to meet its objectives. Kellow (2010) argues that causes include the failure to include the United States, which represents the single largest contributor to GHG emissions, and the lack of any coherent plan beyond 2012. There was also a failure to effectively include developing nations such as China, which are poised to surpass the United States in emissions (Rabe, 2008). The late 2011 Canadian withdrawal in order to avoid financial penalties for failing to meet their goals exemplifies the lack of accountability the Kyoto Protocol provides (Hu and Monroy, 2012). While some nations have met or are close to meeting their goals, some argue that the total effects are negligible in contrast to the overall increase in emissions, and the costs involved are infeasible over the long term (Rabe, 2008; Kellow, 2009). Prins and Rayner (2007) argue that above all, the Kyoto Protocol was ill-conceived as a problem solvable by traditional 'top-down' methodologies such as the creation of a global carbon trading system.

A number of authors identify that effective progress can be made by focusing on 'bottom-up' policy creation. Opportunities for mitigation and adaptation are unique by geography, and giving state and local governments the freedom to enact policy best suited to their situation helps develop initiatives that are both effective and financially advantageous (Burke and Ferguson, 2010). Allowing policy experimentation across a greater number of jurisdictions helps identify ideal solutions unique to different locales. These can then be adapted to different regions and various scales based on their effectiveness (Prins and Rayner, 2007; Lutsey, 2008).

2.1.2 Policy at the Provincial and State Level

While policy and initiatives developed at the federal level in North America have struggled to cause any significant change in emissions trends, progress is being made by state and provincial governments. By 2008, 42 states had developed GHG emissions inventories, 17 of which had set reduction targets similar in design to those in the Kyoto Protocol (Lutsey and Sperling, 2008). Burke and Ferguson (2010) identified that by 2010, most states had initiatives relating to the reduction of GHG. These include opportunities for consumer-level green energy production and grid 'feed-in' programs, renewable energy generation goals, and climate action plans (Selin and VanDeever 2007). Rabe (2008) argues that this trend in 'bottom-up' policy generation seen by states is occurring for a number of reasons. Reducing GHG emission has been seen as economically advantageous, in part due to an increase in events possibly related to climate change that encourages action. Some states identify as being "first movers" (Rabe, 2008, pg. 107), making it a key issue to lead the rest of the nation on climate change action.

Progress seen by Canadian provinces has lagged behind the states, only seeing significant progress in recent years. This is argued to have been caused by the ratification of the Kyoto Protocol and the paralysis experienced by provinces as the federal government set climate policy (Rabe, 2007; Burke and Ferguson, 2010). Nevertheless, by the end of 2009 every province had a GHG emissions inventory and had reduction targets set. Initiatives include carbon taxes, tradable emissions programs between provinces and some states, energy efficiency programs including subsidies and tax rebates to consumers, and public awareness programs on everyday reduction opportunities (Snoddon and Wigle, 2009)

Provincial governments possess unique opportunities in creating and enforcing climate change policy as there is more authority over environmental issues at the provincial level. Management of Canada's natural resources are constitutionally deferred to the provinces (Rabe, 2007). Energy production is also overseen by the provinces. This means that emissions, land use, and energy generation activities can be more closely governed provincially. Examples of this are seen in British Columbia's Climate Action Plan, which was released in 2008, and Ontario's Go Green Climate Change Action Plan from 2007 (Ontario, 2008; BC, 2010).

British Columbia's Climate Action Plan sets a number of ambitious goals including an 80% reduction in GHG from 2007 levels by 2050. It aims to accomplish this through a number of programs and legislation including the Clean Energy Act, which is designed to encourage the production of local renewable energy built through locally made technology and labour. A goal was set for becoming carbon neutral in the government and public sector operations by 2010, which the province met, becoming the first major region in North America to do so. A number of policies regarding building efficiency standards, the use of environmentally friendly materials, and zero net deforestation were adopted. The plan also includes a revenue-neutral carbon tax, where all revenue is returned through tax reductions to the public (BC, 2010).

Ontario's Climate Change Action Plan includes a number ways to address climate change, including setting short to long term 'green targets' for emissions, conservation, and a phase-out of coal-fired energy generation in the province. Related to this is a plan to invest in renewable energy production opportunities for homeowners in the province as a way to include the public and generate replacement load for the coal plants. This will be supported by a significant investment in increasing renewable energy technology sector jobs. Furthermore, a significant investment for improved rapid transit in the Greater Toronto Area (GTA) and Hamilton is planned to be completed by 2020. Finally, a plan to supplement the Ontario Greenbelt Act by planting 50 million trees by 2020 as a carbon sink and other benefits (Government of Ontario, 2007).

Of particular interest is the movement to include the public in electricity generation through feed-in tariff programs and legislation permitting consumers to generate and supply electricity to local grids. This reflects the sentiment by critics that a bottom-up approach may provide a more effective alternative to previous approaches (Victor et al., 2005; Lutsey, 2008; Rabe, 2008). This is exemplified by the implementation of the Green Energy Act in Ontario, described in the next section.

2.1.3 Ontario Green Energy Act

On request of the Ontario Government in 2006, the Ontario Power Authority (OPA) developed a plan for replacing all coal-fired electricity generation in the province with greener alternatives. This plan would phase out coal plants between 2010 and 2014 if energy reliability was not in question. Renewable energy would play an important role in future generation needs with a proposed increase of over 8000MW in capacity by 2025 (OPA, 2006). In response to this the Green Energy Act was passed with the objective of making renewable energy opportunities accessible to small-scale users. It would also improve energy conservation through increased energy-efficiency standards for new buildings and household appliances. It would also encourage job growth with an emphasis on a local ‘green industry’ that supplies technology and labour for these programs. The Act provides a number of policy changes to permit the development of a feed-in-tariff (FIT) program, which incentivises the adoption of renewable energy technologies by businesses and individuals. These changes include adjustments to regulations to permit individuals to connect renewable energy sources to the local power grid, as well as a streamlined approvals process to provide accessibility to small scale programs (Government of Ontario, 2009).

The FIT and MicroFIT (for consumer-scale installations of 10KW or less) programs provide incentives for small-scale photovoltaic installations in the form of tariffs for energy produced and placed back on the electrical grid. Technologies supported include on-land wind, biomass, biogas, landfill gas, water, and both roof-based and ground mounted solar photovoltaic (PV) panels. Individuals and businesses can access the application process through a website where they can investigate the rules and technical information of the program as well as submit and review the status of an application. While information and resources regarding all aspects of the process are provided, it is the responsibility of the user to determine feasibility in terms of hardware cost and energy production capabilities (OPA, 2010).

The program has seen a great deal of interest at the FIT and MicroFIT levels as almost 50 000 total applications have been submitted since August, 2012. Table 2.1 and Table 2.2 show the number of submitted applications, offers of contracts, and commercially operating systems for each technology in the FIT and MicroFIT programs respectively (OPA, 2012a). Tariff rates have changed from their original values set in 2010 to new rates that are applicable as of April 2012. This change is due in part both to the decreased cost of technology since the program's inception as well as increased popularity. In particular the MicroFIT rates for rooftop solar installations less than 10 kilowatts were reduced from 80.2 cents per kilowatt-hour to 54.9 cents per kilowatt-hour (OPA, 2012b). Table 2.3 lists the old rates and Table 2.4 lists the new rates for both FIT and MicroFIT programs.

Table 2.1: Total submitted MicroFIT Applications as of Aug 7, 2012

Source	Total Submitted Applications	In Commercial Operation
Solar PV	39661	157
Bioenergy	39	0
Hydroelectric	0	0
Wind	126	0
Total	**39826**	**157**

Table 2.2: Total activity, FIT program as of Aug 7, 2012

Source	Total Submitted Applications	Contract Offers	In Commercial Operation
Solar PV	9764	2249	314
Bioenergy	131	58	14
Hydroelectric	105	52	0
Wind	299	83	7
Total	**10299**	**2442**	**335**

Table 2.3: Version 1 (August 2010) of FIT and MicroFIT rates

Position	Size Tranches	Contract Price (¢ per kWh)
Rooftop	≤ 10 kW	80.2
	> 10 ≤ 250 kW	71.3
	> 250 ≤ 500 kW	63.5
	> 500 kW	53.9
Ground Mounted	> 10 kW	44.3
	≤ 10 kW	64.2

Table 2.4: Version 2 (April 2012) of FIT and MicroFIT rates

Position	Size Tranches	Contract Price (¢ per kWh)
Rooftop	≤ 10 kW	54.9
	> 10 ≤ 100 kW	54.8
	> 10 ≤ 500 kW	53.9
	> 500 kW	48.7
Ground Mounted	≤ 10 kW	38.8
	> 10kW ≤ 500 kW	35.0
	> 500 kW ≤ 5 MW	34.7
	> 5 MW	11.5

In reviewing the first year of the FIT and MicroFIT programs, Yatchew and Baziliauskas (2011) identified that that there was considerable interest from individuals and developers, with project applications adding to over 15 000MW of proposed electricity generation. The authors attribute this response to the improved streamlining of the application process, preferred access to local hardware and labour suppliers, and attractive, financially advantageous tariff rates. In comparison to FIT's predecessor, the Renewable Energy Standard Offer Program, the authors identified that the proposed supply in the first year of applications was more than double. They attribute this to the 'right-to-connect' policy under the Green Energy Act that sees far more programs being eligible as FIT projects do not require connection directly to a distribution system.

This level of success of the FIT and MicroFIT programs is not without precedent. In a review of solar energy policy, Solangi et al. (2011) remark that over half of the world's photovoltaic (PV) installations are due to FIT programs. Previous and existing FIT programs in Europe have proven to be successful, representing a significant part of climate action plans in Germany, France, and Spain to name a few (Streich, 2011; Solangi et al., 2011). In many of these countries, success has been exemplified by high levels of participation by large scale projects such as 'solar farms', as well as wall and roof-mounted residential PV installations.

2.1.4 Policy at the Municipal Level

Developing and enacting climate change policy at the municipal level provides a number of opportunities not seen at higher levels of government as policies can be designed to cater specifically to the needs and desires of a region's constituents. Municipal government has closer control over energy consumption choices, transportation opportunities including mass and alternative transportation to reduce GHG emissions, and land use decisions that can play a role in mitigation and adaptation opportunities (Zimmerman, 2011). Lutsey (2008) identifies these opportunities as especially advantageous at the local scale as policymakers have greater freedom to experiment with climate change strategies. The lessons learned can then be shared among local governments improving efficiency and alleviating the strain on local governments without resources or opportunities to commit to unproven policy. This is close to the same 'bottom-up' opportunities identified at the state and provincial level as discussed earlier in this section (Rabe, 2008).

Climate change mitigation has been undertaken in a number of ways at the municipal level. Wheeler (2008) investigated mitigation and adaptation strategies at the state and local levels in the United States, finding a number of trends in action. Cities commonly undertake projects to improve efficiency of government resources and to either mandate or encourage its constituents to take action. The author found that initiatives such as requiring Leadership in Energy and Environmental Design (LEED) certification on government buildings, more GHG emission friendly vehicle fleets, and internal environmental audits were common. Requiring a certain percentage of public energy consumption to come from renewable sources was also common.

A number of authors found that at the municipal level, there is a greater focus on mitigation rather than adaptation, with exception to a few cases where potential flooding, the urban heat-island effect, or other issues were seen as important (Wheeler, 2008; Zimmerman, 2011). Wheeler (2008) notes that of the 35 cities investigated, documentation from only five of them contained a mention of adaptation. Zimmerman (2011) identified that urban heat-island reduction and stormwater management as two issues tackled by some cities. New York City has adopted a plan to plant one million trees while Chicago aims to increase tree canopy by 20% by the end of 2020. Both cities have also adopted plans to improve capacity for increased volume and variability of stormwater.

An example in Ontario is the implementation of the Toronto Green Development Standard, which is a set of sustainability goals for all developments built after January 31, 2010. The standard uses a two-tiered system of mandatory and optional requirements divided by low-rise residential and commercial, and high-rise developments. These standards are divided into groups including air quality, ecology, solid waste, water quality and efficiency, and

GHG emissions and energy efficiency. Like many other city-level initiatives, mitigation and adaptation opportunities such as renewable energy and energy efficiency requirements, and stormwater management and urban heat-island reduction are the focal point (City of Toronto, 2010).

Authors have identified that while these initiatives are a step in the right direction, an increase in public engagement is necessary. Wheeler (2008) mentions how some interviewed officials discussed that their constituents are aware of climate change issues but are unwilling or perhaps unable to act. He also points out another common complaint that it is difficult to get the public to attend meetings regarding climate change. A study was performed by Semenza et al. (2008) that interviewed individuals in Houston Texas and Portland Oregon regarding climate change awareness and possible change in behaviour. Of the respective 53% and 37% of respondents who identified as having not taken action, common explanations included the lack of time to act, the lack of financial resources, or that the problem appeared to be too large for individuals to take action on. The authors concluded that moving individuals to change behaviours requires "appropriate educational messages" to "increase awareness about the causes and consequences of climate change." (Semenza et al., 2008, pg. 486)"

2.1.5 Climate Policy as a Spatial Problem

While policies are applied broadly across a jurisdiction due to how government works, their ability to be enacted and resulting impact can vary significantly across space, especially at larger scales. Space is essentially the primary factor that determines who is interested in a problem and the scale at which the problem affects them. Individuals may not relate to a problem to the same extent at the national level as they do at the local level (Carver and Carver, 2003). On an article about the Not in my Backyard (NIMBY) phenomenon, Dear (1992) discusses how proximity plays a significant role in people's perceptions of the significance of an issue to them, where even a space as little as a few city blocks can be the deciding factor toward participation. It is therefore unsurprising to see GIS at the forefront of research on the policy making and decision making process (see: O'Looney, 1997; Malczewski, 2006; Wise and Craglia, 2007).

Sieber (2006) identifies three reasons why GIS is important to these processes. First, information relevant to policy issues typically involves a spatial component, as is the nature of issues found in an area that shares many spatial and aspatial relationships. Second, it has been identified that by involving spatial information that is relevant to a greater breadth of stakeholders, the policy making process can aim to be more accommodating. Finally, Sieber points out an argument made by Wood and Fels (1992) that investigating data and information related to policymaking can provide a result that can more effectively "convey ideas and convince people of the importance of those ideas" (Sieber, 2006, p.491).

The use of GIS to empower decision makers has been received with much debate as some see this as a growth in disparity between officials, stakeholders, and the public (Pickles, 1995). The exclusion of the public in the decision making process served to focus on the needs of the 'haves' versus the 'have-nots'. This was caused by the disparity in technical skill required to operate complex GIS software and equipment, imbalanced political opportunity of decision makers over the public, and the increased ability for the wealthy to affect outcomes in policymaking (Obermeyer, 1998; Pickles, 1999; Talen, 2000). While the merits of GIS in decision making are clear, it also serves to widen the technological gap between those with experience and a considerable amount of training and those without. Thus, the ability for individuals to be involved with issues that interest them relies on their ability to cross this gap (Pickles, 1995; Carver, 2003).

Furthermore, it is argued that the use of GIS has implications other than simply improving the spatial decision making process. The side effect of moving toward a more efficient abstraction of a spatial problem is that the simplified data, parameters, and results have an effect on the decision making process (Sheppard, 1995; Obermeyer, 1998). Sheppard (1995) argues that the GIS process does not simply communicate the issues, but alters their perception. This is because GIS has the ability to visualise and provide results that appear convincing and persuasive, despite the quality of the underlying methodology (Obermeyer, 1998).

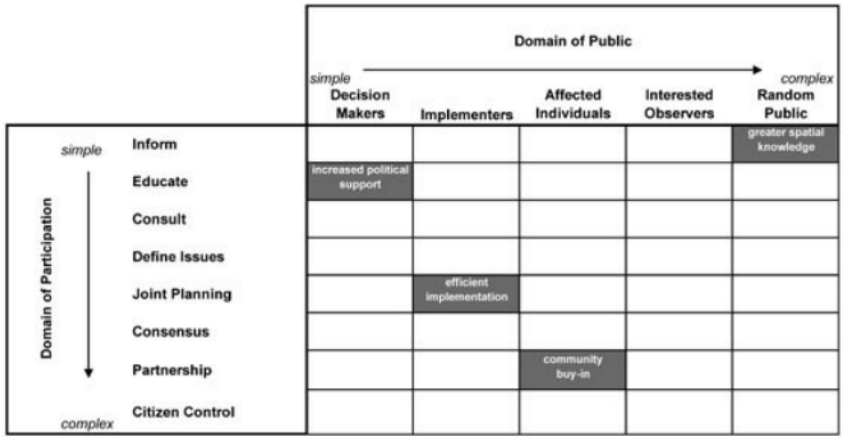
2.2 Public Participation GIS

Public Participation GIS (PPGIS) evolved as a response to the continued discussion on these issues. Formally, it originated at two meetings of the National Center for Geographic Information and Analysis (NCGIA) in 1993 and again in 1996 where members worked to identify how to resolve these observed inequalities in how GIS was used (NCGIA, 1996). The resulting definition of PPGIS was a “variety of approaches to make GIS and other spatial decision-making tools available and accessible to all those with a stake in official decisions” (Schroeder, 1996). It was seen that the ideal next generation in GIS would be more inclusive of all parties, by focusing efforts on identification and inclusion of those who were marginalised by the onset of the use of GIS (Obermeyer, 1998; Carver, 2003).

Since the concepts behind PPGIS are applicable to almost any decision making problem that affects the public, it is no surprise to find their use in a broad variety of subjects. This ranges from traditional problems such as community development planning (Elwood and Ghose, 2001; Hawthorne et al., 2008; Bugs et al., 2010), resource management (Kyem, 2002; Jordan, 2002), and environmental sustainability (Kingston, 2000; Ball, 2002) to name a few. Local scale climate change mitigation and adaptation has also been subject of PPGIS practices (Few et al., 2007). A breadth of examples can be found in Craig et al. (2002) in the form of case studies. Despite many of these issues existing in numerous areas and often across geographic scales, a sole PPGIS design may be ill-suited to exploit the opportunities as well as meet the needs, restrictions, and communicate issues unique to each (Seiber, 2006). Therefore it is important to consider the unique local details of the issue being investigated when developing a PPGIS.

Inclusion of the public in the decision making process also provides an opportunity to take advantage of local knowledge. This type of knowledge differs from traditional knowledge in the sense that it is unique to the people that possess it (Warren, 1991). McCall (2003) argues that this kind of knowledge should be treated as a local resource that is unique to the residents. It is further argued that this knowledge should not be undervalued as primitive and unprofessional in comparison to 'official knowledge', gathered through formal, scientifically sound means (Dunn, 2007). In many cases, local knowledge can provide an invaluable addition to the information used in a PPGIS. However, these data often exist and shared in informal formats including the verbal tradition, shared skills, and unrecorded knowledge of the environment to name a few (Dunn, 2007; Grenier, 1998). These formats are typically incompatible with traditional spatial data acquisition methods and possess a unique challenge to the inclusion of local knowledge in the decision making process (Dunn, 2007).

Resolving these challenges requires a careful investigation of what the needs are for a particular PPGIS. Schlossberg and Shuford (2005) identify how both the 'public' and 'participation' components of PPGIS can be divided into a range of user types attempting to accomplish a variety of goals. These range from simple to complex forms of interaction with a PPGIS, among individuals with differing interests in the issue. Figure 2.1 visualises this relationship in the form of a matrix, where each identified audience type would fall within a cell. When planning and developing a PPGIS for a specific function, it is important to identify where the audience lies in this matrix in order to understand the data and technical needs to be fulfilled (Schlossberg and Shuford, 2005).



Source: Schlossberg and Shuford (2005).

Figure 2.1: Relationship between 'public' and 'participation'

Even with the identification of the audience, communication of data and knowledge is a challenge that stems from the disparity in technical proficiency of stakeholders and the control decision makers traditionally have over data (Dunn, 2007). While PPGIS principles work to be more inclusive of all relevant parties, they do not directly work to resolve the divide between the capabilities of experts and non-experts. Because of this, public participation remained an exercise that was largely shaped and guided by the decision makers, leaving many different groups without inclusion or representation (Aitken and Michel, 1995; Pickles, 1995; Talen, 2000). Talen (2000) argues that PPGIS benefits from following a 'bottom-up' approach where rather than guiding participants' views towards a predefined consensus, the GIS facilitates individual exploration of the issues. "[Bottom-up GIS] (BUGIS) simply aids the dialogue, ultimately expressing whatever representation is most meaningful to a particular group" (p.283).

This movement toward empowering individuals with the ability to be self-driven in the public participation process serves to further democratise PPGIS (Talen, 2000; Carver, 2003). Stakeholders can investigate the dynamics of issues that are meaningful to them and develop an understanding that is hindered by a more heavily structured approach. The goal of this strategy is to strengthen participation through improved communication of issues, encourage more open public involvement, and to make local knowledge more compatible with the decision making process (Talen, 2000). A lot of the possibility to accomplish this comes from the use of Web technologies to share data and GIS capabilities in a more accessible environment. Furthermore, the increase in individual decision making blurs the lines between the realms of PPGIS and spatial decision support, where decision making processes that were traditionally reserved for the experts are becoming more relevant and accessible to the public. Both of these issues are discussed in the next sections.

2.3 Web Mapping and Web-GIS

2.3.1 Background

Web mapping dates back to the early 1990s just after the advent of the World Wide Web. The Xerox PARC Map Viewer was one of the first web maps, serving as an experiment of how interactive data can be served using the hypertext transfer protocol (http). Users could pan and zoom at pre-defined scales, and the server would return generated map images in graphics interchange format (GIF) based on the page coordinates of the mouse clicks (Putz, 1994). This was commercialised by MapQuest in 1996 using essentially the same technology. By 2005, popularity of interactive web mapping was evident as MapQuest had over 47 million unique users. In the same year Google Maps entered the market with a focus on exploiting broadband Internet with a tiled map scheme, permitting a more organic interaction with the map service. This emphasis on ease of use became a driving factor of the evolution of web mapping evident today (Haklay, 2008).

GIS functionality on the Web became possible in the mid-1990s with the advent of a group of technologies known as Asynchronous JavaScript and XML (extensible markup language). Known as AJAX, these combined technologies improved bi-directional communication through asynchronous data transfer and improved client capabilities through use of JavaScript. This improved opportunities for the Web to be used as a dynamic source of data rather than offering pre-generated content using HTML (Ping et al., 2009). In 2000 ESRI released its first web-GIS service called ArcIMS (Internet Map Server) that boasted the ability to toggle the visibility individual layers and perform basic attribute and spatial queries in addition to the map navigation functionality found in web mapping tools (East et al., 2001). The advent of ESRI ArcGIS Server greatly expanded the technical ability for data hosting and access and made nearly all offline GIS functionality publishable to a Web-GIS application either directly through an Application Programming Interface (API) or published Web service. ArcGIS Server supports numerous APIs including JavaScript, Flex, and Silverlight, which greatly expands how GIS data can be accessed and manipulated online, expanding past the map-only and GIS-only environments previously possible (Fu, 2011).

2.3.2 Web Services and APIs

Web services are online interfaces with programming and data assets, designed to be easily accessed by applications over the Internet in an 'open' manner. By using common protocols and data languages, these services can easily be drawn upon by different applications, often simultaneously, as well as in conjunction with other Web services. Designed as a 'black box' component, these services can be accessed regardless of the programming language or design of the client, so long as their input and output prerequisites are met. Web-GIS services are typically divided into two groups: map services and data services. Map services provide read-only map data as a base map or one or more layers (Fu and Sun, 2011). Examples include Bing Maps (http://www.bingmapsportal.com/ISDK/AjaxV7) and ESRI ArcGIS services including both base maps and thematic layers (http://www.esri.com/software/arcgis/arcgis-online-map-and-geoservices/map-services). Data services provide greater access to data, permitting applications to perform actions such as attribute or spatial queries, editing data, geocoding addresses, or other network or spatial analysis functions. In the case of ESRI ArcGIS Server, almost any geoprocessing tool can be packaged as a custom geoprocessing service and accessed by a client application, enabling these services to offer comparable levels of sophistication to their desktop equivalents (ESRI, 2012a).

APIs are a common way to offer a simple way to interact with and have greater control over Web services. Written in one or many programming languages, they allow applications and services to interact by sharing technical details on processes, object types, data structures, and other components related to the desired API functionality. APIs in Web-GIS extend capabilities offered by Web-GIS services by enabling functionality on the client side (Fu and Sun, 2011). For example, the ArcGIS Server JavaScript API enables a JavaScript-based Web application to view a combination of map services in one frame, where the user may dynamically pan and zoom the map. This is done without the end-user being exposed to the sending and receiving of requests and map data (ESRI, 2012b).

Web-mapping APIs, especially the Google Maps API have provided considerable opportunities for businesses and individuals to investigate and visualise data in a spatial manner. The most common method of this seen since 2005 is the combination of multiple sources of data and functionality, known as a 'mashup' (Yu, 2008). While these can include combinations of purely non-spatial data sources, 'geomashups' are able to represent traditionally non-spatial data in a spatial manner (see: Wood et al., 2007). These mashups can be as simple as displaying pins and thumbnails dropped on a Google Maps basemap for each photo in a publicly available album using GPS metadata or the 'geotag'. Obtaining a spatial reference from addresses or location descriptors can often be done, allowing for the generation of mashups from data sources such as Twitter 'tweets' that were not specifically intended for such use (Fu and Sun, 2011).

2.3.3 VGI and Neogeography

These sources of user generated content are termed by Goodchild (2007) as Volunteered Geographic Information (VGI), formalising the phenomenon of individuals developing volumes of spatially describable information, often with no formal training. Suppliers of VGI are often not aware of their participation, as exemplified by publicly available, geotagged photo albums or spatially locatable tweets. These users fall within Unwin's (2005) description of 'accidental geographers' as they unintentionally curate spatial datasets that may eventually be used as a source of mashups or further analysis without their knowledge or participation. Other users, however, are active participants in the VGI process, deliberately offering spatial data for event-specific causes such as disaster relief projects (Zook et al., 2011) or ongoing projects such as Open Streetmap or Wikimapia. (Goodchild, 2008; Fu, 2011)

These are some examples of the 'neogeography' phenomenon, which is the term used for all new forms of non-traditional geography seen in the past decade (Haklay et al., 2008). As Turner (2006, 2-3) describes it, "[neogeography] is about people using and creating their own maps, on their own terms and by combining elements of an existing toolset." If looked at more broadly, this is essentially the democratisation of the toolset of the geographer, as Web technologies transition mapping and GIS capabilities from the experts to the public, not just as consumers but as producers (Dunn, 2007). This new paradigm is not without its own set of novel problems, however. Practices behind mashups and VGI acquisition are a departure from the perceived authority that expert-developed projects enjoy. Scrutinizing data quality and developing standards for trust is a significant challenge that by its nature is in opposition to providing these tools to everyone (Goodchild, 2008; Haklay et al., 2008). Furthermore, this growing wealth of tools and data risks overuse and abuse, leading both to technical complications of mass data consumption and implications of data ownership and copyright issues (Fu, 2011).

The democratisation of GIS is not solely in the domain of neogeographers, however. As discussed in the previous section, PPGIS provides opportunities for enabling the public to be included in the development and execution of a GIS for issues that individuals have a stake in. The use of PPGIS can take advantage of Web technologies by expanding potential audience and altering how the public interacts with the tools and information. Participants who may have previously been discouraged by location and scheduling issues have greater accessibility through 24/7 availability of services that can be accessed on any computer with a web connection (Owens, 2000). From a technical perspective, PPGIS can take advantage of capabilities described earlier including the consumption of various sources of data and tools. Online communication and collaboration among the public is also possible (Fu, 2011). Finally, the public can be given more power to investigate and make use of the tools and methods in the decision making process. This serves to further empower and educate the public on the dynamics of the issues being investigated (Owens, 2000). The implications of this is discussed further in the next section, which introduces spatial decision support systems and how they serve to further democratise spatial decision making processes online.

2.3.4 Spatial Decision Support Systems

As discussed in the section on PPGIS, public participation has traditionally been segmented into a "them and us" (Carver, 2001; p.907) configuration. Decision makers would hold executive power to define the problem and structure the interaction with participants, impacting the extent to which participants could become involved. Part of this process commonly involves the use of spatial decision support systems (SDSS), tools used to define the structure of a multi-faceted spatial problem and aid in the investigation of possible decision alternatives (Shim et al., 2002). Akin to other tools in the planning toolbox such as GIS, the exclusivity of SDSS to experts has affected the ability for the public to be included in decision making processes (Carver, 2001). In the investigation of trends and opportunities in SDSS research, it is important to first define and understand decision support systems (DSS). This is valuable as DSS has existed as a phenomenon for a much longer time and knowledge has been developed that can be applied to SDSS. Shortly after the time of inception of SDSS, it was identified that DSS research and developed practices were upwards of 15 years ahead (Densham, 1991).

DSS are computer-based programs that are designed to aid decision makers with defining and investigating the dynamics of a problem. Problems can be placed on a spectrum between unstructured and structured, which describes how clearly defined the parameters are. A fully structured problem would require little to no input by the decision maker, while semi-structured and unstructured problems are dependent on external evaluation and expert judgment (Gorry and Morton, 1971). A DSS is used to better structure problems in order to free decision maker to focus on the unstructured parts of the problem (Densham, 1991). While research on DSS dates back to the 1960s, this was largely conceptual due to computational limitations. Individual decision making began to develop due to the advent of the personal computer in the 1980s, enabling a wider array of problems to be investigated (Keenan, 2003). In addition, the increased power of the personal computer allows computationally complex spatial data and analysis techniques to be used in decision support.

SDSS extends this problem solving paradigm to include spatial parameters in the decision making process. Goodchild (2000) identified SDSS as a combination of the analytical capabilities of DSS and the cartographic and spatial data management capabilities of GIS technology. SDSS differs from GIS as problems tackled by SDSS are typically non-deterministic and are often much more complex and uncertain in nature (Malczewski, 1999). This means that in addition to the identification of the problem and design of the information system, expert knowledge is required as a dynamic component of the workflow. This lets users investigate a range of alternatives to problems that are often semi-structured by nature of their spatial complexity (Rinner, 2003).

SDSS is commonly implemented as an extension of GIS software through the use of exposed functionality, often through an API. Due to the increased demand for extensibility, application vendors are moving toward the use of standard languages and practices. ESRI, for example, makes use of Visual Basic for Applications, and more recently Python for out-of-the-box customisation and scripting. In addition they provide APIs for Java, C++, and Microsoft .NET (Keenan, 2006). Numerous SDSS have been developed on these platforms and are typically designed for specific issues (eg. Laudien et al., 2010). Additionally, some SDSS are built using pre-made environments that aim to package functionality in an easily customisable manner. These commonly focus on problem archetypes that are common between geographical regions but each with their own specific issues. Examples include

CommunityViz (Walker and Daniels, 2011) and Geonamica (Hurkens et al., 2008), both of which focus on planning decision support efforts.

2.3.4.1 Web-Based SDSS

Use of SDSS on the Web serves to take advantage of the same opportunities available to general Web-GIS and PPGIS applications. These include taking advantage of a broader audience, easier user accessibility and interactivity, and a more natural interaction with various Web-enabled data sources and services (Sugumaran and Sugumaran, 2007). The design of Web-SDSS applications parallels their offline counterparts as they typically take advantage of existing APIs and frameworks. However, the nature of using a client-server relationship changes how they are implemented.

Web-SDSS is commonly implemented through a three-tiered client-server relationship. This includes the client, the middleware, and the data storage tiers (Peng and Tsou 2003; Rinner, 2003). The client is the local component, which typically consists of the user interface rendered in the user's web browser. In the 1990s the client would generally be an HTML interface or Java applet that could provide user interface (UI) components not easily possible with HTML. While the client can be designed simply as an interface between the user and the data and SDSS functionality (known as a 'thin-client'), it has become increasingly common for data and functionality to be made available locally. This is known as a 'thick-client' and takes advantage of improved technical capabilities available from web browsers, plugins, APIs, and improved bandwidth. The middleware tier consists primarily of the Web-server and services that configure and permit communication between the server and the client. This makes the application's website accessible, providing the HTML, JavaScript, or plugin data for download and initialization by the web browser (Jankowski, 2008). Common examples include Apache and IIS (Rinner, 2003). The data storage tier consists of the databases and database software that permit access and manipulation of stored data. In the context of Web-SDSS or Web-GIS in general, this is commonly a Web-GIS server that facilitates the storage, access, analysis and manipulation of spatial data. These functionality are typically made available through an API that exposes GIS server functionality to the Internet through the Web-server where applications can make calls to Simple Object Access Protocol (SOAP or Representational State Transfer (REST)-based services. Common GIS servers include ESRI ArcIMS and ArcServer.

The use of a client-server model allows applications to be updated ad-hoc as no local component is installed manually. The Web-server will request that the client removes the Web application from its cache and re-downloads it. Furthermore, web applications enable clients to return to a 'zero state' after each use as no local preferences or files are changed. Both of these also serve to improve compatibility and usability among the target audience as in most cases the only requirement is a modern Web-browser (Sugumaran, 2007).

Rinner (2003) performed an investigation of numerous Web-SDSS projects and identified that the use of thin-clients and thick-clients changed over time with improvements in Web technologies. Examples of purely server-side Web-SDSS with a very thin-client for interface include a multi-criteria site planning application (Menegolo and Peckham, 1996) and a crop management investigation tool (Jensen et al., 1998) both use HTML forms for submitting data and HTML for the viewing of results. By the next decade, applications began to use Java applets more commonly, and functionality began moving from the server to the client. This included basic interface tools such as investigating and manipulating geometry and their attribute data seen in collaborative land use change assessment prototype by Sidker and Gangopadhyay (2002). Some client-only applications exist as self-sustaining Java applets. These can also be run as Java applications external to a web browser. Jankowski et al. (2001) developed an applet with a number of multiple-criteria evaluation techniques. In this example the Web is used simply as a repository for the application and does not play a role in its use as all data and functionality is downloaded to the client.

Making decision support technologies available to the public has a number of challenges associated with it. DSS has evolved as a technology used by trained experts, and therefore has previously seen little consideration for communication of functionality and data to non-experts as professional software typically focuses on breadth and depth of functionality. These issues parallel those identified in PPGIS research where it is suggested that HCI will become increasingly important when developing these tools (Haklay and Tobon, 2003).There are also some technical challenges stemming from the Web being originally developed to serve data on-demand from any location in hyperspace. DSS typically sees users saving session data and continuing or referring to stored settings/decision scenarios at a later time. While there are workarounds available in the form of storing session data locally or providing a server-based account, these solutions add to the already complex user workflow (Bhargava et al., 2007). These issues are resolved in part with new web software development kits (SDK) such as Microsoft Silverlight and Adobe Flex (Ping, 2009). These SDKs focus on a media rich user experience with an emphasis on user interface development. This is seen especially in Flex with its interface pedigree in Adobe Flash.

2.4 Modeling Insolation

While the engineering and technical details of photovoltaic panels do not fall within the objective of this research, it is important to understand the primary factors that affect their feasibility in an urban environment. In simple terms, PV panels produce direct current (DC) electricity when energy in the form of photons emitted from the sun interact with the electrons in the crystalline material in the panel, exciting them into a higher energy state (NEED, 2011). The amount of insolation that reaches the solar panels can be modelled by accounting for the daily rotational and annual orbital cycles of the earth, atmospheric attenuation and scattering, and local topography that causes a shading effect. Details on the factors involved with PV placement and efficiency are discussed in Chapter 3. There are numerous models that use different methodologies for calculating total insolation, each with benefits and drawbacks for different spatial scales, accuracy requirements, and availability of requisite data.

Dean et al. (2009) discuss a number of methods commonly used to develop solar radiation datasets for use in PV feasibility Web-applications. The two sources for these data are from measured ground or satellite sources, which are interpolated to a coarse spatial resolution, or using a model that accounts for surface topography at a finer resolution. The selection of these methods depends on the needs of the application and availability of data necessary for the modeling process. As data sources are generally location and situation dependent, it is more important to identify which of these two approaches are more ideal for local-scale investigation of PV feasibility.

Measured data sources are typically derived from meteorological stations or satellite-based atmospheric transmissivity modelled data for a large area. In the United States, the Typical Meteorological Year (TMY) dataset currently uses 1454 meteorological stations as well as satellite-modelled solar data available at a 10km resolution (Wilcox and Marion, 2008). Natural Resources Canada's (NRCAN) equivalent photovoltaic potential and solar resource map data are interpolated from 144 meteorological stations to a 10km resolution (Pelland et al., 2006). Being freely available, these datasets can easily be used with PV efficiency models without further pre-processing requirements. However, the coarse resolution limits the measured approach to either making assumptions or requiring further knowledge of the local rooftop properties including roof area, aspect, slope, and nearby shading (Wilcox and Marion, 2008; Dean, 2009).

Due to its low spatial resolution, measured solar resource data cannot accurately describe local scale topographic variability. A modeling approach has been adopted to produce comparable solar radiation data for applications that require a higher spatial resolution or where radiation measurements are not available. Solar radiation models typically combine an irradiation model with atmospheric and topographic models to generate a grid of total insolation for the study area at a user-selected time interval (Fu and Rich, 2000; Suri and Hofierka, 2004).

In a study of two early models, *SOLARFLUX* and the *Atmospheric Topographic Model* (*ATM*), Dubyah and Rich (1995) identified three considerations to be made when designing and selecting a radiation model. In contrast to *SOLARFLUX*, *ATM* is a group of multiple applications that do not exist within a GIS. This creates a level of complexity when attempting to perform further GIS-related tasks on resulting data while preserving user customisability of inputs. The ability to interface the model with other applications is important for the same reason. Computational intensity was also identified as a concern as model complexity greatly increased processing time.

Recent models typically exist within a GIS, providing an improved user interface as well as a greater flexibility for use with other processes. *r.sun* is implemented as a free model in the open source GRASS GIS environment. It has two usage modes that enable the calculation of instantaneous solar radiation or the calculation of solar radiation over a given period of time. While internal estimates can be made for a number of factors including solar declination and atmospheric transmissivity, *r.sun* is designed for the user to input the study area latitude as well as a number of atmospheric values including turbidity, ground albedo, and clear-sky transmissivity indices (Suri and Hofierka, 2004).

The *Solar Analyst* model included in ESRI ArcView and ArcGIS software packages is built with an emphasis on the topographic factors relating to solar radiation, generating upwards-facing viewsheds that describe local shading effects for each cell in the study area grid (Suri and Hofierka, 2004). This enables the user to balance computational intensity with shading detail by determining the resolution of this viewshed as well as the number of directions the algorithm looks in to detect topographic obstructions (Fu and Rich, 2000). However, *Solar Analyst* only accounts for atmospheric transmissivity as a single broadband value for the entire study area, limiting its use to simpler atmospheric modeling and larger spatial scales where atmospheric variability is minimal.

2.5 Identified Relationships between Fields of Study

Through investigation of each of these fields of study, a number of relationships are identified. Top-down climate change policy is argued to be ineffective at enabling individuals to participate in mitigation and adaptation opportunities. Recent changes in policy seen in North America encourage a bottom-up approach by developing a foundation for programs that incentivise voluntary action (Victor et al., 2005; Rabe, 2008). At the municipal and city-levels, initiatives are being undertaken that leverage opportunities unique to that scale. This includes climate change mitigation strategies such as renewable energy generation, energy efficiency and GHG reduction. In some cases adaptation strategies are being investigated and undertaken that focus on local issues such as the urban heat-island effect, stormwater runoff, coastal flooding concerns, and others (Zimmerman, 2011). It has been argued that moving forward the public needs to take an active role in adaptation and mitigation strategies. This is accomplished by greater communication of the issues and policy development that empowers individuals to take action (Owens and Driffill, 2008).

There is a growing movement of individuals becoming active participants in the decision making process of issues traditionally tackled by experts. This is in part due to the opportunities brought about by Web technologies as well as a growing need, in some cases, for public participation that was not previously achievable. This is realised by making individuals aware of the issues and providing them with the tools and knowledge required to take action. In the context of climate change, this is seen primarily at the local scale where individuals have a greater opportunity to participate (Semenza et al., 2008; Wheeler, 2008).

The advent of the Web and related technologies developed over the past two decades have created an online environment where the sharing of data and communication of issues is commonplace among interested parties. Web-based geographical information and tools are being used by non-experts at a growing pace, paralleled by the increased ability for GIS tools and methods to be used online. This has created an environment where users can exploit these capabilities despite not having a formal education in geography if proper considerations are made regarding the structuring of the user interaction experience.

The use of Web-SDSS as a means for individuals to communicate and explore opportunities made possible through initiatives, government policy, and new technologies is not new. Many Web-SDSS applications have been developed to investigate green initiatives, especially green energy generation. Reviews of a number of these applications have identified that most involve a linear decision making process where individuals can navigate to an address and retrieve data pertaining to feasibility (Dean et al, 2009; Blakey, 2010). These applications have done a great deal to move research forward on the use of Web-SDSS and Web-PPGIS to overcome the socio-political challenges described in this chapter. A number of opportunities have been identified for further improving the approaches taken in developing these applications. Those identified include:

1. In response to the efficacy of bottom-up policy development, empower individuals to be able to participate in adaptation and mitigation efforts through education on local-scale issues.
2. Include the public in the decision making process for issues relating to climate change policy and the development of initiatives.
3. Take advantage of the Web and related technologies to facilitate the inclusion of the public in these decision making processes.

2.6 Summary

This chapter investigated a number of fields of research including climate change policy at different levels of government, the use of Web technologies to communicate climate issues, and methods for including the public and enabling them to participate in the decision making process. Relationships between these fields were identified, providing a number of opportunities to improve approaches used in developing Web-applications for investigating solar potential. Details relating to the Ontario Green Energy Act and resulting FIT and

MicroFIT programs are discussed. Methods described in literature for modeling insolation for use by solar potential Web-applications are also investigated.

Chapter 3 describes the best practices and methods selected to generate the necessary data for, and build a Web-SDSS for investigating climate change mitigation and adaptation opportunities in Toronto, Ontario.

Chapter 3 – Data and Software Design

This chapter details the methods behind designing the required data and application components for SunSpot. Section 3.1 discusses how solar resource rasters are modelled using ESRI Solar Analyst and identifies methods for developing the topographic and atmospheric datasets required to do so. Section 3.2 presents the City of Toronto as a case study for generating solar resource data. The rationale behind this choice is described along with a description of the available data for this research. Section 3.3 details the methodology behind generating the surface models and atmospheric transmissivity values required for Solar Analyst. It then details the solar resource data generation workflow for the study area. Section 3.4 discusses the functionality requirements and design of SunSpot, including a description of additional data required for the Web-application to function. Finally, section 3.5 provides a summary of this chapter and introduces Chapter Four.

3.1 Solar Resource Data Development

A number of commonly used methods for obtaining solar resource data were investigated in Chapter 2. These are divided into two categories: measured data from one or a combination of ground and satellite-based sources, and data modeling approaches that use secondary datasets to derive solar radiation estimates. In this investigation, it was determined that the modeling approaches were superior when investigating local-scale solar potential. These approaches are designed to account for local topographic shading, which makes up a significant portion of surface solar radiation variability at the local level.

Of the available modeling approaches, ESRI Solar Analyst was selected for a number of reasons. In contrast to a number of the older models, Solar Analyst is integrated with a GIS software package, making interoperability with other geoprocessing and visualisation tools a simpler process. This also provided a more recent, user friendly interface as well as the ability to easily integrate the modeling process in scripts and workflows such as Python and Model Builder. Solar Analyst has proven to be a suitable choice as it has been used in similar research to much success (Dean et al., 2000). Finally, Solar Analyst was used by this author for research for an undergraduate thesis, which resulted in increased experience with the software (Blakey, 2010).

3.1.1 Solar Analyst Methodology

Solar Analyst models total broadband surface radiation for a study area by calculating total direct and diffuse radiation for a user-selected period of time. Direct radiation is the insolation that reaches the surface without being scattered by the atmosphere. It is calculated by Solar Analyst based on the position of the sun, atmospheric attenuation, and the fraction of the measured area that is not obstructed by local topography. Diffuse radiation is the portion of insolation that is scattered by the atmosphere, thus incident on the surface from many directions. It is calculated using either a standard overcast diffuse model or a uniform diffuse model as selected by the user, which changes how zenith affects the radiation flux. When combined, a raster representing the 'global radiation' is created, where each cell in the study area reflects the total modelled insolation in watts per square metre over the user-selected duration of time. The details in this section are all sourced from the Solar Analyst User's Manual 1.0, written by Pinde Fu and Paul Rich (2000).

3.1.1.1 Sunmap, Skymap, and Viewshed

In order to model direct and diffuse radiation, three hemispherical maps are generated in raster format. These maps represent upwards-facing views of the sky from each cell in the study area. The study area bounds are defined by the extents of the topographic model. The centre represents maximum zenith while the circumference represents the horizon (Figure 3.1). The sunmap and skymap are used to calculate solar flux from different portions of the sky, while the viewshed describes topographical obstructions for a given cell, caused by surrounding topographic features such as hills, trees, and buildings. A sunmap and skymap are calculated once and are reused for each cell in the study area, while a unique viewshed is calculated for each cell.

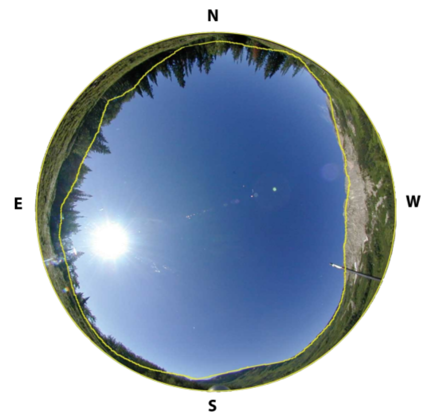


Figure 3.1: Visual example of a hemispherical viewshed (adapted from ESRI Help)

The sunmap is a series of uniquely identified segments in a hemispherical view, each of which represents an equal amount of time in a day when the sun was in that part of the sky. This represents the track of the sun's movement through the sky and make up horizontally arched bands. Depending on the number of days in the user-selected study period, more of these bands are present, relating to the seasonal shift of the sun. In the example in Figure 3.2a, each sector represents a one-hour interval of the sun's position as it changes over the span of a month, based on a day interval of seven. Values for the hour and day intervals are selected based on a balance of processing time and the accuracy of modelled results.

The skymap is an evenly divided hemispherical raster used to calculate diffuse radiation from all directions. It is segmented evenly by azimuth and zenith into sky sectors, which are uniquely identified by attribute table values. The example skymap in Figure 3.2b is divided into eight evenly spaced zenith and azimuth divisions, each of which represent 45° azimuth and 11.25° zenith. Like the sunmap, the number of user-selected divisions is a compromise between processing intensity and precision of the results. Too few sectors mean an over-generalisation of how solar radiation is calculated.

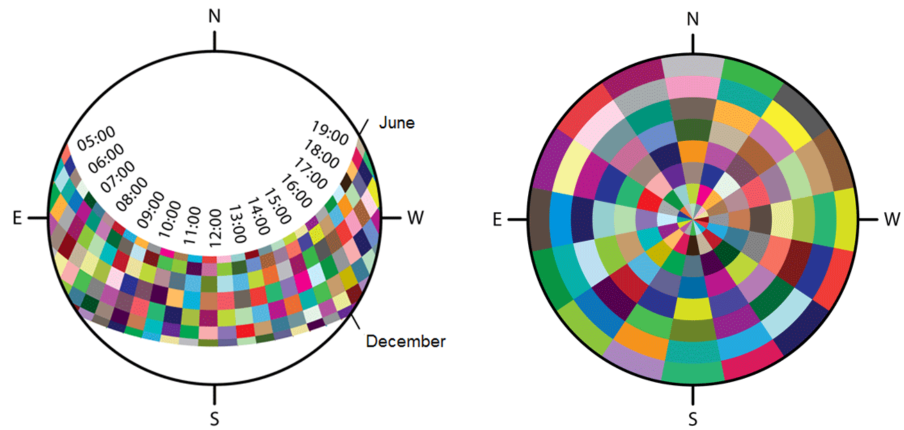
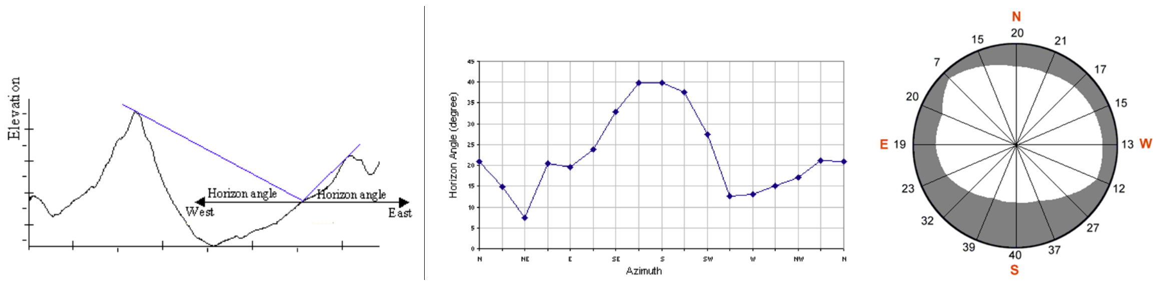


Figure 3.2: (a) Example sunmap and (b) skymap (adapted from ESRI Help)

The viewshed is a hemispherical raster with binary values that correspond to the presence or absence of topographic obstructions. A viewshed is generated for each cell in a raster topographic model that is provided as a requirement of the Solar Analyst model. Each viewshed is generated by an algorithm that compares the elevation of the cell being investigated with those nearby by calculating the zenith angle to any higher valued cells. This is conducted for opposing directions in pairs as visualised in Figure 3.3. These are translated into a series of values of the minimum horizon angle in degrees for each azimuth direction investigated. These values are finally converted to the same hemispherical projection as the sunmap and skymap (Figure 3.2). The number of directions to be checked this way must be a multiple of four to accommodate how the algorithm works as it is based on compass directions and must be subdivided evenly. Too few directions results in simplified data with a visually apparent ‘striping’ effect seen in Figure 3.4 while too many can greatly hinder processing time.



Source: ESRI Help

Figure 3.3: (a) Directional obstruction detection as (b) graph and (c) viewshed

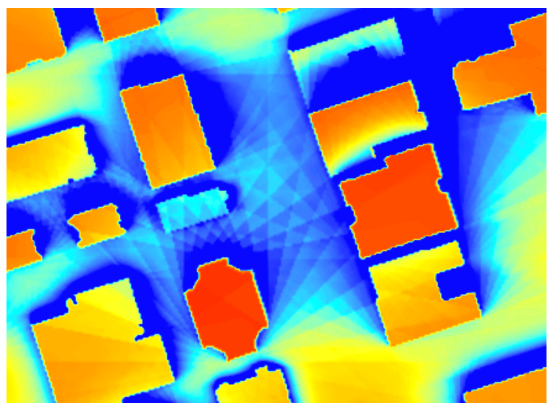


Figure 3.4: Example striping effect caused by small number of viewshed directions

3.1.1.2 Direct Radiation

Direct radiation is calculated for each sector of the sunmap using a formula based on the size of the sector, the position of the sun, atmospheric attenuation as a broadband value, and surface orientation. The atmospheric calculation is done using a simple transmission model that reduces the solar constant by an amount based on a transmissivity value and air depth. The solar constant is a generally accepted value of 1367 watts per square metre, representing the annual average solar radiation at the top of the atmosphere. The mathematical details of this formula are described by Fu and Rich (2000) in the Solar Analyst manual. Methods for obtaining broadband atmospheric transmissivity values are described in section 3.1.3.

Once all sunmap sectors have corresponding radiation values for the user-selected period of time, the viewshed for each study area cell is overlaid to determine which sectors are visible. The proportion of the visible part of partially obstructed sectors is also determined. An example of this overlay is seen in Figure 3.5a.The corresponding radiation values for these sectors are added together to obtain the final value used to populate the direct radiation raster.

3.1.1.3 Diffuse Radiation

Diffuse radiation is calculated for each sector of the skymap using either a uniform diffuse or standard overcast diffuse model. The uniform model is typically selected by the user for generally clear sky conditions and assumes that radiation is even from all directions. The overcast model is used for cloudy or 'overcast' conditions, and assumes an empirical relationship between zenith angle and diffuse radiation flux (Fu and Rich, 2000). These models determine total radiation using equations that factor the time interval, proportion of visible sky and incident angle of each sector to the surface. The user inputs a value for the proportion of diffuse global radiant flux, which is described by Fu and Rich (2000) as being typically between 0.2 and 0.7 for clear sky and cloudy sky conditions respectively. Determining the proportion of each sector of the sky that is visible is done by overlaying the viewshed for each cell on the skymap (Figure 3.5b) Specific details on these overcast models are described in Rich (1989) and Pearcy (1989).

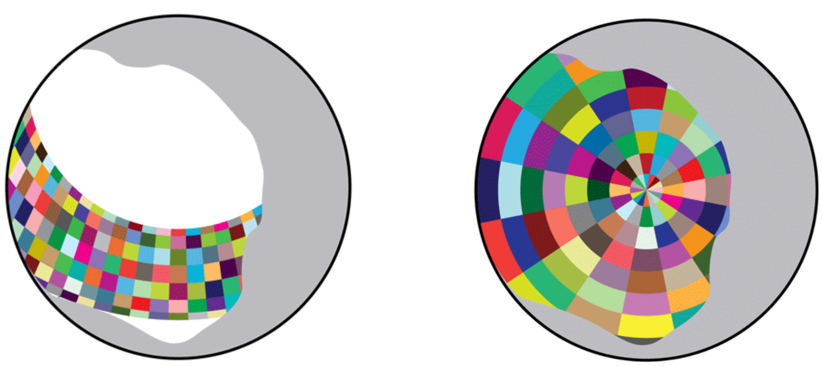


Figure 3.5: (a) Sunmap with viewshed overlay and (b) skymap with viewshed overlay

3.1.2 Topographic Model Development

Solar Analyst requires a digital surface model (DSM) that effectively describes features at the scale level being investigated. A DSM is a raster model where each cell contains a discrete height value of a continuous surface. A DSM is unique from other topographic models as it is inclusive of all human-made and natural surface features such as buildings and vegetation. At small scales, a topographic model based on contours or a triangulated irregular network (TIN) can effectively represent how a surface's topography affects solar flux over a large area as these features are insignificant. At large scales, however, minor features have a larger impact in affecting surface solar radiation. Developing a topographic model that is suitable for investigating rooftop solar potential requires an accurate representation of building rooftops and surrounding features that impact global solar flux. For rooftops, this includes the position, aspect, and slope of roof faces as they play a role in total incident radiation and self-shading (Dean et al. 2009).

While there are numerous methods for generating a DSM, three approaches described in literature on solar resource modeling are investigated. By briefly discussing the methodology behind each, an understanding of their benefits and drawbacks when used in the context of solar resource modeling can be developed. This aids in determining the ideal methodology for generating a DSM based on the constraints of a specific case, depending on available data. The approaches described in this section include the use of vector-based three-dimensional (3D) geometry, aerial light detection and ranging (LiDAR) scanned surfaces, and the generation of planimetric buildings by extruding footprints based on an average height value.

3D Building Models

3D building models have been commonly used for urban planning practices such as investigating land use development, viewshed analysis, air quality, and other climate issues. The transition from physical models to computer-aided-design (CAD) based models and the integration with GIS have further improved analytical capabilities (Hu et al, 2003). In the context of urban solar radiation modeling, 3D building models are an attractive source of topographic data due to their highly precise representation of roof structure. This also provides an opportunity for the modelled data to be cleaned up, removing spurious features and noise (Jakubiec and Reinhart, 2012).

The development of 3D building data requires real-world measurements and various levels of manual and automated processing. Hu et al. (2003) investigate a number of data sources and methodologies for generating these data, including the digitization of ground or aerial imagery, stereoscopy, and ground or aerial LiDAR scanning. These sources have the potential to perform well in producing accurate 3D building data, but have high financial and data processing costs associated with them. The exclusion of features that can obstruct sunlight such as trees is also a concern, requiring further data sources to compensate if those features want to be modelled. Furthermore, as Solar Analyst is designed to use a raster surface model, the precision of continuous vector data would be lost when the models are converted.

There has been little use of 3D building models with Solar Analyst. In a review of solar resource modeling approaches, Jakubiec and Reinhart (2012) investigated 11 solar potential mapping websites. Of these, five used Solar Analyst to model solar resource data. None of these used 3D models to generate the DSM. In this review, a 3D model dataset of over 17 000 buildings in the city of Cambridge, Massachusetts was used both with the RADIANCE / DAYSIM raytracing engine and Solar Analyst. The authors identify that 3D models are best suited to vector-based raytracing modeling approaches rather than Solar Analyst as the latter approach does not account for surface and wall reflectivity and cannot model vertical surfaces.

LiDAR

Pulse-based airborne LiDAR is a remote sensing technology used to generate digital elevation models (DEMs) by measuring the three-dimensional position of discrete points on a surface. These points are measured using a high frequency laser pulse mounted on an aerial platform. A rotating mirror is used to reflect the pulses across a swath along the flight path. The distance from the platform to the surface is measured by the time delay of the laser. This is converted into a point with x, y, and z coordinates using on-board global positioning system (GPS) and inertial measurement unit (IMU) data to solve the point's position trigonometrically (Jensen, 2007). A raster surface model can then be derived from these points by identifying the highest point in each cell of a grid and applying its elevation value to that cell. Various interpolation techniques can be applied to fill any holes that may exist in the data.

Since modern airbone lidar systems can measure points at a very high rate, resulting point clouds are very high density, often at less than one metre average spacing (Baltsavias, 1999). This results in the ability to resolve not only rooftops but other features such as trees without requiring additional sources of data. Furthermore, the LiDAR scanner can return multiple elevations as the beam is not discrete to a one-dimensional point in space but rather extends over a period of time and a two-dimensional area on the surface. Commonly known as different 'returns', a discrete pulse may produce a number of responses as the pulse reflects off different surfaces. This is most commonly caused by vegetation such as trees where a number of returns are recorded through the canopy structure. The first return (FR) is the first response recorded and generally represents the top of the tree. Intermediate returns may be recorded for reflections in the tree canopy and the last return (LR) is the final response and typically corresponds with the surface. By excluding all returns but the last, a point cloud and resulting DSM can be generated that represents 'leaf-off' conditions where penetrable tree canopies are ignored (Figure 3.6).

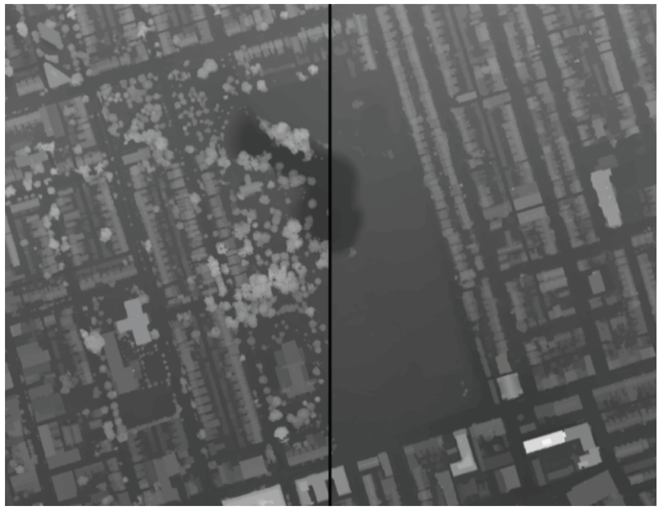


Figure 3.6: FR and LR based DSMs showing leaf-off (right) and leaf-on conditions (left)

There are a number of drawbacks to using aerial LiDAR data as a source for generating a DSM. Steep terrain and dense buildings often block the beam's path, resulting in 'shadow' areas where topographic data was not recorded. In areas with many tall buildings with a lot of glass or metallic surfaces, reflection of the beam can create false return values, creating a large amount of noise in the data. LiDAR point clouds are also very large in file size and can require a considerable amount of time and effort to process and develop a DSM from (Dean et al., 2009).

Examples of projects that use aerial LiDAR data for Solar Analyst include the New York City Solar Map website and the Solar Salt Lake Project (New York, 2012; Salt Lake City, 2012). Both of these are Web-GIS applications that let users query rooftops and calculate estimated photovoltaic potential.

Extruded Buildings

In contrast to the previous two methods, the vertical extrusion of building footprints provides a much simpler alternative to generating a DSM. Building footprints are generally more readily available and less expensive than aerial LiDAR data or imagery, and require only a basic digital terrain model (DTM) and building heights. The DTM represents the basic topography of an area, excluding any surface features, and are typically generated from contour and spot height data or the production of a TIN. In order to maintain the horizontality of each building when combined with the DTM, either they are added to a modified TIN where footprint-touching triangles are flattened, or the grid cell values are normalised for each footprint area.

While this approach is computationally simple and requires data that are typically available at a lower cost than alternative methods, there are a number of drawbacks. First, it makes the assumption that all buildings have flat rooftops. This can impact solar radiation modelling as the sun's apparent position changes through a year and has different northern or southern maximum extents depending on latitude. Second, it makes the assumption that all buildings share a uniform shape from the base to the top. This means that some buildings that decrease in area toward the top may have an over-representation of roof area.

An example project that uses this data source for the Solar Analyst model is the City of Boston Solar Map (City of Boston, 2012). Much like the Salt Lake City and New York City applications, Solar Boston lets users select rooftops or draw custom areas to query PV feasibility.

3.1.3 Atmospheric Data Approaches

Not all solar radiation reaches the surface directly as some is scattered by the atmosphere to produce diffuse radiation, some is absorbed by the atmosphere, and some is reflected back into space. The proportion of radiation affected in these ways is based on the properties of the atmosphere above the study area, which varies over a given year. To account these differences in attenuation through the year, Solar Analyst uses an optional value called the clearness index *(kt)* for each user-defined period of time. This value ranges between 0.0 and 1.0 and describes the ratio of broadband radiation that makes it to the surface where 0.0 would be none (Nakada et al., 2010). While investigating atmospheric variability and how it affects surface solar radiation is not a focus of this research, it is useful to include clearness indices in the process of developing solar resource maps. This helps improve the accuracy of the resulting solar datasets by accounting how *kt* varies over a given year in a given region. *Kt* can be modelled by using surface radiation measurements or an atmospheric model that relates a number of measured atmospheric properties to overall clearness.

Kt is directly related to the ratio of broadband solar radiation at the top of the atmosphere and the surface. This ratio can be calculated by measuring surface global radiation and subtracting it from a measurement of solar radiation at the top of the atmosphere. Since total insolation at the top of the atmosphere is generally consistent, the solar constant of 1367 W/m^2 can be used instead of a measurement. Global surface radiation is typically available from meteorological stations and is averaged across numerous years to minimize the impact of seasonal anomalies (Kumar and Umanand, 2005). Modeling *kt* using atmospheric properties is done using complex atmospheric models that describe how different properties affect the transmission of solar radiation through the atmosphere. Properties commonly include site air pressure, precipitable water content, ozone, nitrogen dioxide abundance, aerosol optical depth, and turbidity coefficients. Gueymard (2003) presents an assessment of a number of atmospheric models and how they use these properties to calculate *kt*.

3.2 Case Study: City of Toronto

A case study is performed that tests the methodology behind urban solar resource data development and the design and implementation of a Web-SDSS for investigating these and other data. The City of Toronto, Ontario was selected as an ideal candidate for reasons described in this section. The target audience for the study is also discussed. This case study provides a foundation for obtaining suitable data and generating solar resource data required for the Web-SDSS.

3.2.1 Study Area Description

The City of Toronto is located in the southern region of Ontario, Canada on the northwest shore of Lake Ontario. It is located approximately 60 kilometres northeast of the City of Hamilton (Figure 3.7). Toronto was incorporated from the Town of York in 1834 and is the capital of the province. Following World War II the city and surrounding municipalities saw considerable growth and underwent a number of governmental changes. This included the federation of 12 surrounding municipalities with the city in 1953 and the merging of seven municipalities with their larger neighbours in 1966. In 1998 these remaining six municipalities, the City of Toronto, York, East York, North York, Etobicoke, and Scarborough were merged into one, becoming the City of Toronto that exists today (City of Toronto, 2012a).

Figure 3.7: Location of case study in Southern Ontario

Toronto is the largest city in Canada with a population of over 2.6 million in 2011. Including the four nearby municipalities of Durham, Peel, York, and Halton, the Greater Toronto Area has a population of just over six million (Statistics Canada, 2012). The city's population is spread across 140 neighbourhoods which cover just over 630 square kilometres in area (City of Toronto, 2009a). The composition of these neighbourhoods varies from the very dense commercial of the central business district located at the waterfront to suburban neighbourhoods where dwelling single-family and semi-detached homes as well as townhouses are common (City of Toronto, 2012a). There are over 2200 high-rise buildings (a height of over 35 metres) in the city, most of which are residential (Emporis, 2012). Toronto has 8000 hectares of green space including parks, valleys, woodlots, beaches, and golf courses. These areas include 3.5 million of the city's 10 million coniferous and deciduous trees (City of Toronto, 2012b).

3.2.2 Study Area Selection Rationale

The research in this thesis is part of a larger project that was conducted and funded by members of the Geomatics for Informed Decisions (GEOIDE) program. GEOIDE is a Canadian program with the goal of building a broad community around the field of geomatics from academic institutions within and outside of Canada (GEOIDE, 2012). GEOIDE Project PIV-32 investigates visioning tools and community decision making processes for local climate change issues. This project focused on four study areas: Vancouver, British Columbia, Calgary, Alberta, Clyde River, Nunavut, and Toronto, Ontario.

Toronto faces a number of issues relating to climate change adaptation and mitigation. Many of these were discussed in the first section of Chapter Two. Increasing energy demands through a growing population, the urban heat-island effect, the need for cool living spaces, and storm water management issues are some of the challenges being faced today and in the near future. City and municipal policy and initiatives such as the Toronto Green Standard aim to tackle some of these issues through environmental requirements for future developments (City of Toronto, 2010). The Ontario Feed-in-Tariff program is another initiative that encourages the renewable generation of energy at the local scale (OPA, 2010). As discussed in Chapter Two, these initiatives aim to take advantage of local opportunities while tackling issues that are particularly important to Toronto's environmental sustainability.

The City of Toronto is an ideal study area for investigating rooftop PV generation as it possesses a range of building types including a central core of high-rise buildings surrounded by residential neighbourhoods of medium and low density dwellings. This variety is necessary when investigating rooftop feasibility as local topographic shading plays a significant role in total available insolation in a given year. Furthermore, a number of partners in the area including the City of Toronto and Optech Inc. have provided useful data including building footprints as well as contour and LiDAR topographic data. In addition, the City of Toronto's Open Data Project makes additional datasets such as land cover data easily available (City of Toronto, 2009b).

3.2.3 Data Sources

This section describes a number of available datasets for this study area that are relevant to this research. These were obtained from a number of sources including publicly available catalogues from the City of Toronto as well as data donated for research purposes from government entities and private companies. Detailing the available data serves to develop perspective for the decisions made when generating solar resource data in contrast with the ideal practices as described earlier in this chapter.

Topographic Data

Topographic data required to develop the DSMs for Solar Analyst are available from a number of sources for different parts of Toronto. These areas are naturally divided into two groups: the downtown area where a number of different data types form an overlapping but inconsistent coverage, and Black Creek in the northwest where LiDAR data are available for almost the entire neighbourhood. Due to the divide in data types, spatial discontinuity, and varying data quality, the methodology for generating DSMs for both areas is different. For this reason, these areas will be discussed separately and will be identified as 'Downtown' and 'Black Creek'.

The Black Creek data are a LiDAR point cloud in a standard LAS format that was recorded by an Optech aerial LiDAR system. The point cloud covers the majority of the Black Creek neighbourhood in the north west of Toronto. These data have an average point spacing of just over one metre and are classified as first, last, and two intermediate returns.

The Downtown data has three sources for building heights, each of which cover a different, but often overlapping area centred on the downtown core of Toronto. Building footprint data with single height values were developed by RMSI. This feature class begins downtown on the waterfront and covers a six-kilometre-wide swath that extends due north for approximately 12 kilometres or just past Eglinton Avenue. Additional building height data were made available from the City of Toronto Urban Design department in the form of an ESRI feature class that was converted from 3D CAD drawings. This feature class contains polygons with individual heights for each building component including multiple polygons for complex rooftops. The Urban Design dataset consists of buildings for the majority of the downtown area as well as some buildings along Yonge St. in North York. Finally, LiDAR point cloud data from Optech Inc. was made available for eight overlapping east-west swaths, covering approximately 35 square kilometres of the downtown area. To supplement these data sources when developing a DSM, an ESRI feature class of contour lines with a one metre interval was made available by the TRCA for the entirety of the City of Toronto. Extents of these data sources are displayed in Figure 3.8.

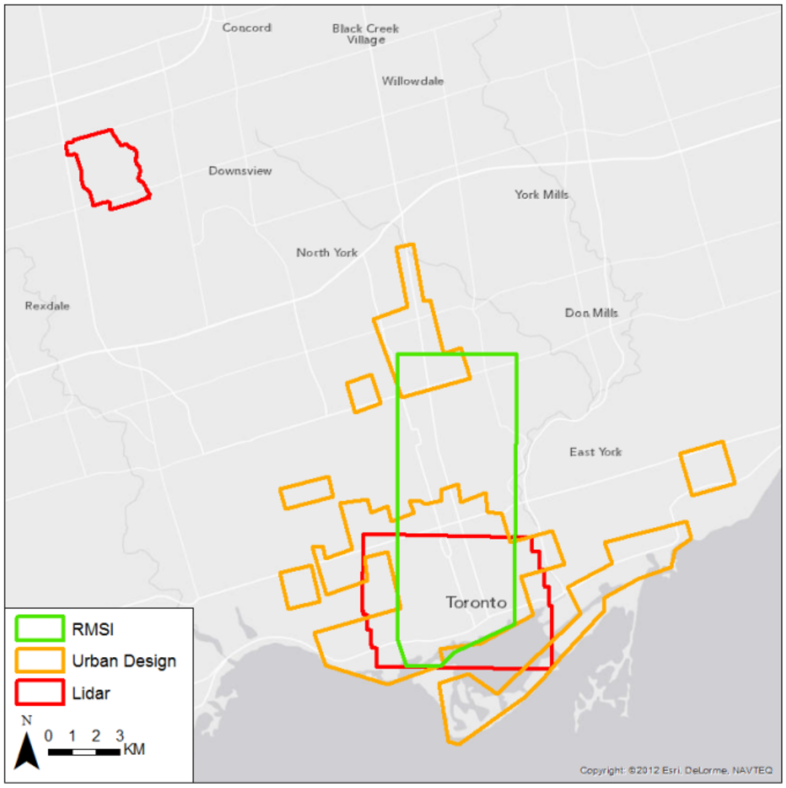


Figure 3.8: Data extents for each topographic source

Atmospheric Transmissivity Data

As discussed in Section 3.1.3, the broadband transmissivity values required by Solar Analyst can be calculated from average net irradiance for each month. These data are available from the University of Toronto at Mississauga's (UTM) Department of Geography in the form of hourly measurements in millivolts that are converted to watts per square metre. These values were measured by a net radiometer and recorded to comma separated text files and are available online for dates between November 1999 and November 2012 (University of Toronto, 2012). In some cases there are missing data values for multiple days that have been annotated as null values. These need to be considered when averaging the same months from multiple years together, which is done to account for variations between years.

Land Cover Data

Land cover data that covers the City of Toronto is available in raster format from the city's Open Data Project. Originally developed in 2009 as part of the Urban Tree Canopy Assessment, this raster is divided into eight classes: tree canopy, grass/shrub, bare earth, water, buildings, roads, over paved surfaces, and agriculture (City of Toronto, 2009b). This dataset was developed using a semi-automated process where 0.6 metre panchromatic imagery captured from the QuickBird satellite is classified using a combination of ERDAS Imagine and eCognition software. This process uses object-based image analysis to identify classes based on shape, size, length, texture, and other non-spectral properties. The results were then manually verified and edited by experts where necessary (Henry, 2012).

Surface Temperature Data

A project undertaken by the Earth Science Sector of Natural Resources Canada produced surface temperature maps of Toronto to assess the impacts of the urban heat-island effect. Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (ETM+) measure energy radiated from the surface in the thermal infrared spectrum between 10.4 and 12.5 µm. Using a method that accounts for effects such as off-nadir measurements and atmospheric upwelling and downwelling, cell values for the imagery are converted from digital numbers to land surface temperature (LST) in degrees Celsius. The resulting products are images that are interpolated to 30 and 60m for TM and ETM+ respectively for six times between 1987 and 2011 (Maloley, 2009).

Landsat thermal data were first geometrically corrected using Geobase road network data as a reference. The eight bit digital numbers were converted to radiance values using gain and offset calibration values available at the United States Geological Survey (USGS) Landsat website. These were then converted to LST values using an inverse Planck function, tested to be accurate within plus or minus 2.0 °C (Schott and Volchok, 1985). This methodology did not correct for atmospheric transmissivity and assumes each cell to have an emissivity value of 1.0 (Maloley, 2009).

3.2.4 Identification of Audience

While traditional SDSS are developed with a specific audience in mind, the online nature of SunSpot greatly broadens this potential audience. SunSpot is not a PPGIS in the traditional sense as it does not actively seek or facilitate a bi-directional communication of knowledge and is not oriented for a specific public policy or decision issue promoted by a government. Nevertheless, lessons in the identification and classification of the desired audience can be learned from PPGIS practices.

Identification of the desired audience and its constituent user types is important when determining how to optimally build SunSpot. Those who consume Web-GIS resources are expanding beyond traditional 'experts' to include members of the public. As identified in a review of literature on public involvement by Schlossberg and Shuford (2005), these user types can vary considerably along two dimensions: what role they play as a member of the public and their intended objective in using the Web-GIS. In the context of SunSpot, one user may be interested in learning how much of their property is green space, while another may be looking to determine if they should further investigate the opportunity of installing rooftop PVs for their home. In this example, the needs of the users vary considerably as one is an interested individual looking to become more informed and educated while the other is a decision maker looking to consult data and tools to aid their process. Building an application that attempts to cater to the needs of all audiences will result in a tool that is without focus and may not successfully meet the needs of any user type. Including the data and functionality required to satisfy a large variety of needs causes the application's design to become too complex. Like many desktop applications, increased functionality almost always increases the cost of entry.

Based on the goals set out for SunSpot, the overall audience includes individuals with an interest in climate change adaptation and mitigation opportunities and their dynamics in the city of Toronto. More specifically, this audience is divided among user types with different needs:

- Members of the public who are curious about the local factors of climate change in Toronto. These users seek to develop a stronger understanding of these issues by investigating relevant data and performing basic analysis to investigate results.

- Decision makers at a broader scale who are interested in investigating dynamics relating to the Toronto Green Standard. In this case, SunSpot would primarily play an educational and informative role as opposed to being a focused SDSS.

Due to the broad range of user types including members of the general public as well as potential decision makers who might identify as 'experts', SunSpot must be designed to be accessible and understandable to those without previous GIS experience. This means that an emphasis must be placed on data design and interface usability that intuitively communicates functionality and meaning without the need for a significant amount of training or education on the basics. From a human-computer interaction (HCI) perspective, these relate to the cognitive issues of supplying advanced functionality and data to non-experts (Haklay, 2010). Examples of this include keeping the UI simple and free of excessive tools or data displays when not necessary, using existing conventions in web mapping those users will have previous experience with, and using symbols and conventions that are intuitive to the general public. However, in order to meet the needs of the decision makers, doing so must not exclude advanced functionality and data presentation that might be critical in the decision making process.

The City of Boston Solar Map is a prime example of these conventions as it initially loads with few UI elements displayed. The map is navigated using the scale bar and mouse to pan and zoom, which is identical to the behaviour of popular Web maps such as Google and Bing Maps. Common symbols such as the sunlight, leaf, and wind turbine icons with corresponding orange, green, and blue colouring are used to represent different green energy types (Figure 3.9a). The New York City Solar Map also shows the same design considerations as the initial map view is simple and shows few UI elements. The navigation tools are also similar to popular Web maps and basic icons are used to describe selecting a building (a cursor), drawing an area (a cursor with a polygon) and clearing the selection (an eraser) (Figure 3.9b).

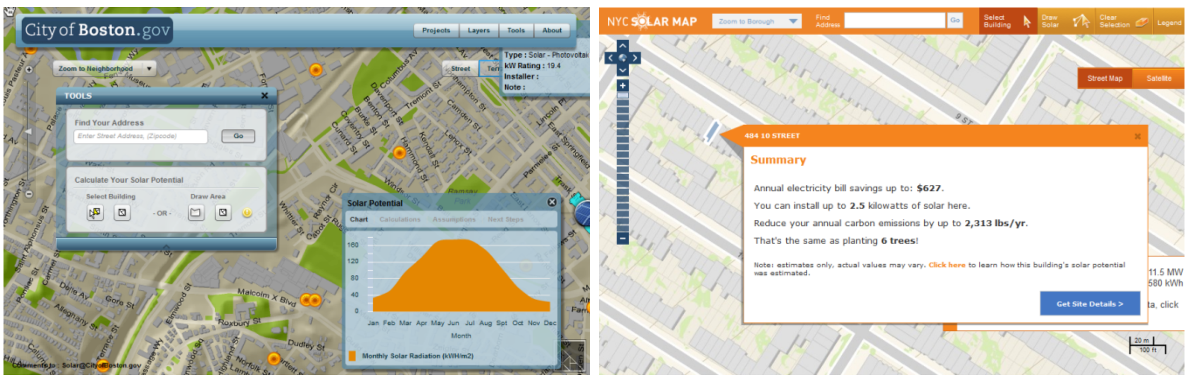


Figure 3.9: (a) Solar Boston and (b) NYC Solar Map Web-GIS select building results

It is assumed that all users will have previous experience with basic web mapping techniques such as map navigation. In addition, SunSpot is designed with the expectation that users have a basic understanding of the broader issues of climate change in Toronto. For example, the application does not aim to educate users on the basics of UHI or green energy, but rather guides their understanding of their impacts and the opportunities that exist at the local level. A basic understanding of these issues can be developed by providing a background on the issues as well references to additional information on the Web using a more info page.

3.3 Solar Modeling of the Study Area

The previous section described the available data for the study area including the topographic and atmospheric data required for solar resource modeling. This section describes how these data are processed to generate DSMs and atmospheric transmissivity values that are then used to generate solar resource data. First, DSMs are produced for both the Downtown and Black Creek areas using different methods that result in flat-roof and LiDAR based models respectively. Second, broadband atmospheric transmissivity values are calculated for twelve months using the available surface radiation measurements from UTM's metrological station. Next, these data sources are used with the Solar Analyst model in ESRI ArcGIS to produce the solar resource datasets in raster format for each month. Finally, building footprints are populated with total monthly and annual solar resource data by adding the total values of all pixels within each footprint. These footprints along with the solar resource rasters are published to ArcGIS Server as map services. The specific configuration settings are described along with the rationale behind their selection. Figure 3.10 illustrates these steps, each of which will be described in detail in the following sections.

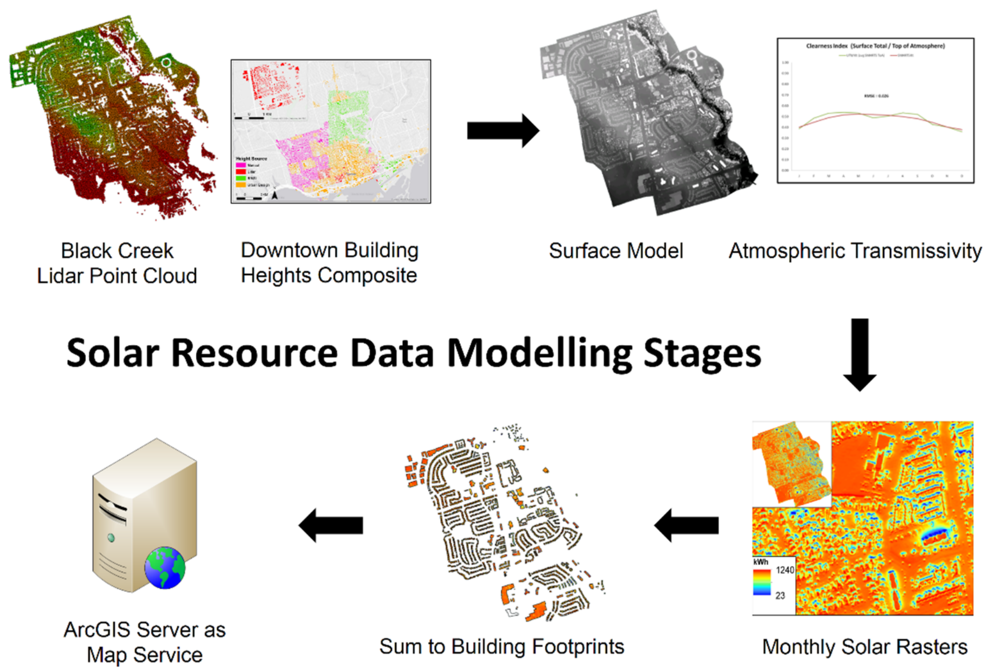


Figure 3.10: Conceptual workflow for generating solar resource data

3.3.1 Downtown Topographic Data Processing

The surface model for the downtown area was developed by combining a DTM with extruded building footprints. The DTM was created in ArcGIS using the *topography to raster* spatial analysis tool to interpolate contour lines (ESRI, 2012c). The DTM was then flattened under each building footprint in order to prevent extruded building heights from being unintentionally sloped. This was done by identifying building footprint areas as individual zones using the Zonal Statistics tool and determining the average height in each zone (ESRI, 2012d). This height was then committed to every cell value in each zone.

The extruded building footprints were developed using the City of Toronto's Property Data Map (PDM) building footprints that were given height values based on one of the data sources described in the previous section. A model was developed that describes the priority in which each building height data source is used based on data quality and availability. The use of PDM footprints as the building outline and repository for heights was selected. Compared to the RMSI and Urban Design footprints, they were the most complete in terms of study area coverage.

If available, LiDAR-based heights were used to develop surface model by combining each of the eight downtown swaths of point clouds and converting to a raster DSM with a one metre spatial resolution. This conversion was done using LiDAR Analyst, an extension built for ArcGIS by Overwatch Systems. Points classified as last return were used to develop the raster in order to include only rigid features such as buildings and not potential overhanging tree canopy that would result in an overestimate of building height. The Zonal Statistics tool was used to find the average height for each building footprint with a buffer of negative one metre. The buffer was used to exclude all edge heights which may be a measurement of the height of a LiDAR pulse response from the wall instead of the rooftop.

Taking priority over both of these sources, Urban Design values were used where available. Multiple height values for many buildings existed for complex roofs that either had multiple modelled faces or, often in the case of downtown commercial structures, had multiple roof segments. These were simplified to the maximum height value using a model that converted these features to points and determined the highest point in each footprint. If none of these sources were available, RMSI heights were used.

The extent of these data was determined to be smaller than desired, including only the downtown core and a small amount of surrounding area. The decision was made to expand this study area using a manual approach for two reasons. First, a broader study area would be more inclusive of different property and building types as the smaller area was predominantly high and medium rise buildings. This assures that a larger sample of low-density dwellings such as single family and semi-detached homes are included in the study. Second, this would provide a preliminary investigation on the challenges and opportunities of using data from multiple sources to generate the required dataset. To accomplish this, additional surrounding neighbourhoods were manually given building heights based on building type and available aerial photography. While this method does not provide values that are as accurate as other data sources, it provides a close enough estimate of building heights to model the impacts of day/night cycles and seasonality. Figure 3.11 shows the resulting building footprints colour coded based on their data source.

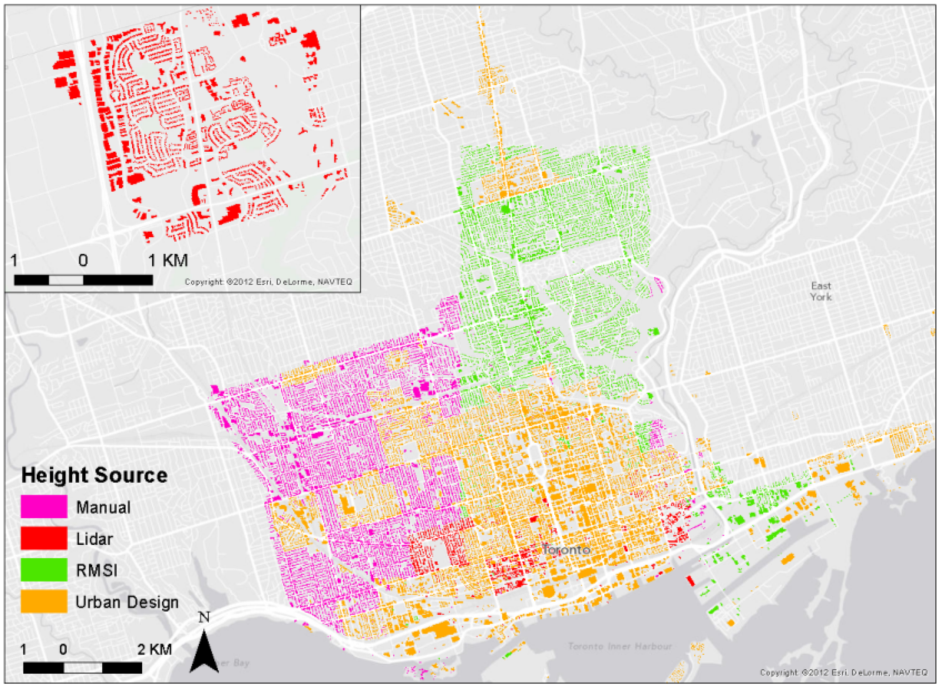


Figure 3.11: Building footprints with height values, colour coded based on data source

In order to mitigate edge shading issues, an additional 200 metres of buildings were included in the study area and given heights. While these heights are part of the group that was manually estimated, a test on an area with actual heights found that the impact on results for rooftops in the study area was negligible. Further research is required to investigate the significance of using true building heights versus generalised heights based on building type when developing solar resource data. This work falls outside the objectives of this research. An example of the final surface model generated for the downtown study area is presented in Figure 3.12.

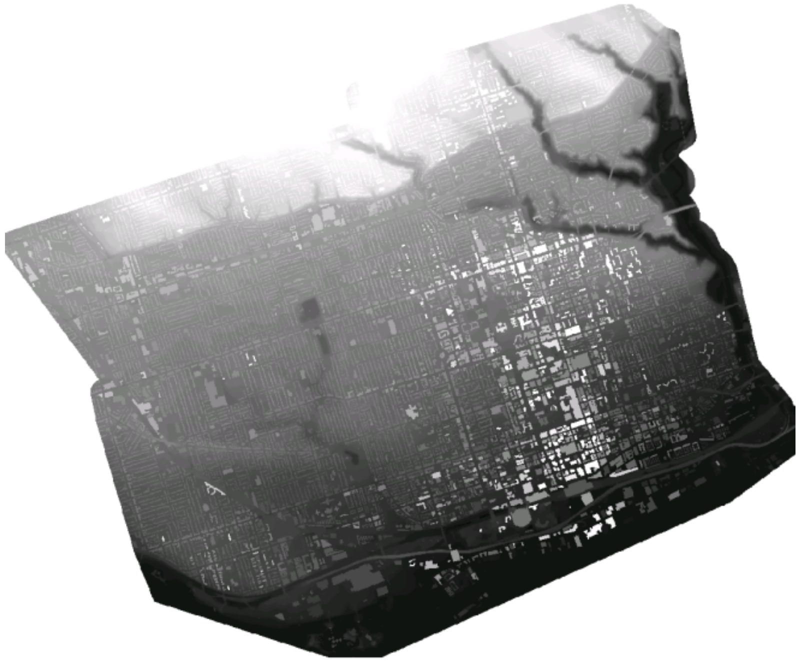


Figure 3.12: DSM of downtown study area

3.3.2 Black Creek Topographic Data Processing

Topographical and building height data for the Black Creek neighbourhood was developed from discrete return aerial LiDAR data provided by Optech Inc. The LiDAR Analyst Extension for ArcGIS by Overwatch Systems was used to process these data and determine individual building heights for the building footprints as well as to develop the DSM for the study area. The individual values are used for reporting heights in SunSpot, while the DSM is used as the required surface model for Solar Analyst.

Calculating individual building heights requires the generation of a bare earth model, which is a DTM that is generated by removing features such as buildings, vegetation, and vehicles from a LiDAR-generated DSM (Li et al., 2004). LiDAR Analyst develops a bare earth model through a supervised process of identifying which points in the point cloud represent the surface. This is done by generating a first return and last return raster used to determine non-rigid structures such as trees (where there are multiple returns) and detecting sharp changes in elevations where there are not (building walls). These rasters were created at a one-metre resolution by filtering the point cloud by their coded return values. The resolution was selected as the average spacing between points was slightly over one metre. This maximizes the spatial resolution of the resulting raster while minimizing the number of empty cells that need to be filled. Cells with no last return point were coded with the first return point. The user investigates the results visually and makes adjustments where the automated process misinterprets steep hills as buildings or where buildings are too noisy and are interpreted as hills. The software then repeats this process with the user-contributed reference data making adjustments to the results. An example of this process is displayed in Figure 3.13, where a point is placed at the centre of each pixel that is believed to be the surface. The colour of the points represents the base height.

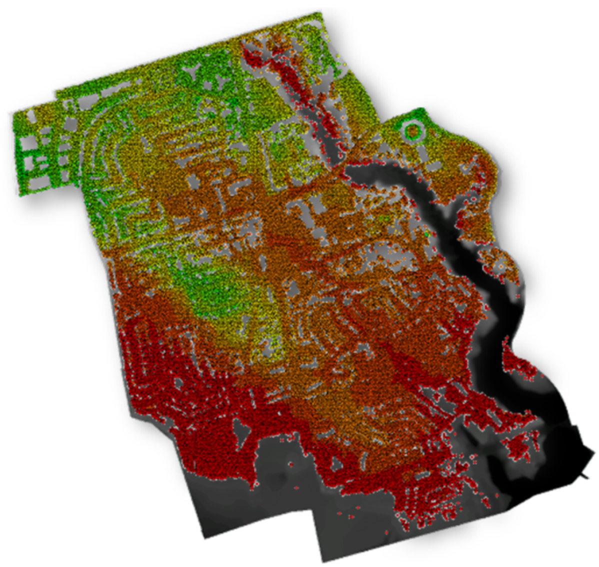


Figure 3.13: Intermediate visual results when generating a bare earth model

The bare earth model is then subtracted from the first return raster to create a raster of non-surface features and their heights. Building footprints (described in a later section) are used to extract only buildings from the area. The maximum height in each footprint is then determined and committed to an attribute value for height.

The first return raster derived from this process is also used as the DSM required by Solar Analyst as it contains all surface features including buildings and trees. The lack of topographic data beyond the edge of the study area causes nearby cells to be incorrectly calculated as having no obstructions nearby, which can greatly overestimate the total insolation received at these areas. This is alleviated by expanding the DSM's bounds by 200 metres in all directions to retain local shading effects for buildings in the study area. This raster is seen in Figure 3.14. 200 metres was selected as a suitable distance through a trial and error process that identified a reasonable distance relative to diminishing returns. Unnecessary area greatly increases the required processing time by Solar Analyst.

Figure 3.14: First return raster of the Black Creek neighbourhood used as DSM

3.3.3 Atmospheric Data Processing

Surface radiation data obtained from UTM's metrological station was used to generate one *kt* value for each of the twelve months as required by Solar Analyst. Described in greater detail earlier in this chapter, these values are the total solar radiation incident on the surface for each hour. *Kt* can be calculated by finding the ratio of this value and the solar constant of

1367 watts per square metre. In order to minimize deviations from the seasonal norm, the 2008 and 2009 years were averaged together. The 2010 or more recent years were incomplete at the time of this data processing and previous years contained numerous data errors and omitted periods of time. While further processing could be done to overcome these problems to obtain a larger sample, the significance of atmospheric transmissivity on final results is not an objective of this thesis. These values serve to bring the *kt* values closer to the regional norm instead of using Solar Analyst's imposed default value of 0.5 for every month (Fu and Rich, 1999). Table 3.1 shows the monthly *kt* values used for the Solar Analyst process.

Table 3.1: Average 2008/2009 *kt* at UTM's meteorological station.

J	F	M	A	M	J	J	A	S	O	N	D
0.39	0.49	0.53	0.54	0.53	0.49	0.50	0.53	0.52	0.43	0.40	0.36

3.3.4 Execution of Solar Analyst Model

Two Solar Analyst models were developed using the DSM for the Black Creek and Downtown areas in the Toronto study area. In addition to the topographic model and atmospheric transmissivity values, this model required a number of parameters to be configured. These parameters affect how Solar Analyst produces and uses the skymap, sunmap, and viewsheds described earlier in the chapter. These govern a balance between computational intensity and precision of the output data. While data accuracy or precision are not being investigated in this research, finding a suitable balance is helpful for the generation of results that are reasonably accurate and are visually intuitive. Finding this balance was achieved by performing a number of tests on small portions of the study area and investigating how the numerical and visual results compare with the change in processing time. Adjusting some of the values from their defaults resulted in a better data product while maintaining a reasonable processing time.

The skymap was set to a default of eight azimuth and zenith directions, which divided the sky into areas by 45 degrees and 11.25 degrees respectively. The choice to use the uniform atmospheric model meant that an overly complex skymap would not provide superior results as all segments were simulating proportionally equal amounts of diffuse radiation. The sunmap was set to one-hour intervals for each day and 14-day intervals for each month. The viewshed was set to look in 32 directions for topographic obstructions. Each of these maps was represented using 200 by 200 pixel rasters. Higher resolution rasters can reduce effects caused by square pixels representing the rounded hemispherical sky, but greatly increases processing time. The 12 atmospheric transmissivity values described in Section 3.3.3 were used instead of the default value of 0.5 for each month. This helps improve the accuracy of the monthly solar radiation raster values, as 0.5 slightly overestimates clearness during the summer and greatly underestimates it during the winter.

This model was executed a total of 24 times, once for each month for each of the two areas in the study area. Outputs were saved to hard disk in ESRI GRID format with a spatial resolution of one metre, which is identical to the input DSMs. For investigatory purposes, all three optional outputs were also saved. These include direct radiation only, diffuse radiation only, and total sun hours; a raster that represents how many hours each cell received either direct or diffuse sunlight. This was completed using two workstation computers, each of which using an Intel i7 Quad Core CPU and 12 gigabytes of RAM. In order to overcome the lack of multiple core support by ArcCatalog, six instances of the model were processed concurrently on each computer with six of the eight cores each committed to an application thread. Excluding the idle time between checking output results and beginning the next twelve instances, the entire processing time was approximately 120 hours.

3.4 SunSpot Web-SDSS

SunSpot is a Web-SDSS that lets users investigate urban rooftop PV feasibility in parts of Toronto as well as examine factors related to UHI including urban land cover and surface temperature at different scales. This is done by providing Web-GIS functionality that lets users visualise and conduct basic decision support functions on data relating to these issues. This includes calculating estimates for potential electricity generation, FIT and MicroFIT estimates of financial incentives, and potential carbon offsets if solar PVs are used. Users can also visualise and investigate how land cover relates to surface temperature in an area or along a user-defined travel path.

This section describes the design process for SunSpot. First, the functionality required by the web application to meet its intended goals is identified, followed by the rationale for the software API that was used to develop SunSpot with. Second, the desired application architecture is described, providing details on how SunSpot will be modularised in a logical manner. Third, the data needed to achieve the required functionality is described along with processing steps taken to make it usable by SunSpot. Finally, the design of each component of SunSpot is described along with a rationale for the choices made in their design.

3.4.1 Functionality Requirements

In order for users to investigate rooftop PV feasibility, the solar resource data must be provided in a manner where meaningful values can be investigated at the proper scale. Many users may not intuitively appreciate values presented in watt-hours per square metre. Conversely, using FIT values in estimated dollars saved over a year as well as estimated carbon reductions is more intuitive to the individual. SunSpot requires a component that lets users easily investigate these values for individual rooftops or specific areas on a rooftop.

Testing the efficacy of investigating local-scale climate change issues such as UHI can be done by providing tools for users to bridge issues with their local perceptions. This can be accomplished by letting users investigate land cover and how it relates to surface temperature. In addition, enabling users to investigate how surface temperature changes along a possible travel route can shed light on how land cover and tree canopy cover especially can play a role in urban temperature and comfort.

There are a number of components required to support these functions, which include controls for visualising the data investigated as well as controlling and navigating the map frame at different scales. At the building level, an address locator can be used for individuals to query and zoom to a specific address. When investigating issues across a neighbourhood, a list of available neighbourhoods in the study area can allow quick access by the user. Providing well-designed controls for data visualisation is important in order to provide users with the opportunity to investigate them in a manner that is not easily subject to user confusion.

3.4.2 API Rationale

SunSpot is written in ActionScript as an Adobe Flex web application that runs in any modern Web browser with the Adobe Flash plugin installed. It uses the ESRI ArcGIS Server 10 API for Flex, which lets the application access geographic data that are stored in an ESRI geodatabase and published to a server as map services. The API also provides common GIS functions for viewing and querying visual and attribute data as well as access to server published geoprocessing services that can make use of almost any ArcGIS tool.

The choice of using the ArcGIS Flex API over the Silverlight or JavaScript APIs was made for a number of technical and practical reasons. The ArcGIS JavaScript API was used to develop a previous web application that investigated photovoltaic feasibility (Blakey, 2010). It was identified through the development process that while the JavaScript API provided the same technical opportunities, building an easy to use interface was a greater challenge. JavaScript depends on HTML for the visual components, which requires further products such as the Dojo API for rich media features. Furthermore, HTML is compiled by the web browser, which can result in different visuals and interface behaviours depending on the browser and version used. Microsoft Silverlight is relatively new as the first version was released in 2007. It is designed to provide a rich media web experience akin to Flash and also requires a browser plugin. However, at the time of project inception there were fewer online resources and support readily available for the development process.

3.4.3 Application Architecture

SunSpot extends an existing open source web application framework published by ESRI called the ArcGIS Viewer for Flex or 'Flex Viewer' as it will be referred to from here on. The Flex Viewer is designed as a generic application framework where functionality, usually in the form of interactive tools is grouped logically into various modules. Modules exist either as UI elements that are always visible or as 'widgets' that contain the elements in a container, which opens and closes independent of other modules. Widgets generally consist of tools and data that are used for specific, self-contained tasks, and therefore can be bundled together and expand as required. An example widget is the Solar Calculator window in the bottom-right of the screen in Figure 3.15. It is designed to contain all the tools and information required for a specific workflow. In contrast, an example of a non-widget module is the group of navigation buttons to the left of the screen, which would be used more often and in conjunction with other application functionality.

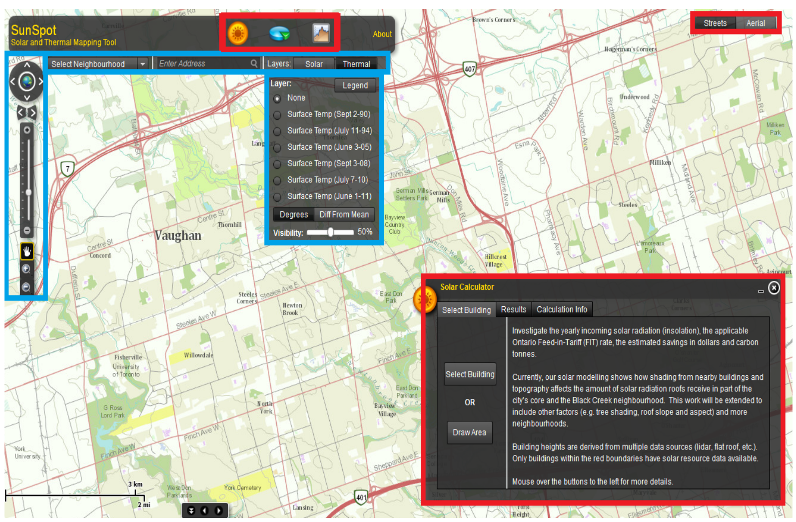


Figure 3.15: SunSpot with widget and buttons in red and modules in blue

A modular approach is ideal for applications that do not follow a linear workflow as it enables users to access functionality in any order. This allows the overall user workflow to be unstructured, while retaining a highly structured workflow inside a widget if desired. It also serves to keep the number of graphical elements visible at the initial application state as low as possible, minimizing complexity. As seen in Figure 3.15, each widget can be opened from a dedicated series of buttons and can be closed or minimized in any order. Widgets can also be configured to float freely, giving the user some control of the application layout, or bound to an area of the screen.

SunSpot makes use of this modular approach to split functionality into two categories. The first category consists of modules that are designed to be available at all times and accessed regularly throughout a user work flow. Some of these include navigation tools for zooming and panning the base map, a list of neighbourhoods for panning to, and lists of data layers to display and adjust the properties of. The second category consists of widgets that contain the data and tools required for specific analytical processes. These processes encompass a large portion of the decision support functionality of the web application, supplemented by the modules, which are always available.

3.4.4 Data Development

3.4.4.1 Building Footprints

In order to expedite the process in which users investigate photovoltaic feasibility on rooftops, building footprints were used as the base geometry for calculating total solar potential. Once each polygon's attribute data are populated with monthly and annual insolation values, buildings can be queried through a simple attribute lookup rather than using a geoprocessing task, which can consume a considerable amount of server time. Building footprints for Toronto were obtained from the Property Data Map (PDM) dataset from the City of Toronto's Catalogue of Survey Mapping Products.

A model was developed that calculated the total solar radiation for each month in each building footprint in both study areas and committed the results to fields for each month. These values can then be queried by the web-application, which performs client-side calculations to produce solar resource, financial, and environmental estimates. Details on these calculations are described in a later section. These queries are considerably faster and less server intensive than the geoprocessing tasks required when calculating solar potential on-demand.

The percentage of direct rooftop obstruction by tree canopy cover was calculated using the 2007 Toronto land cover dataset. Described in greater detail earlier in the chapter, this dataset was developed using a 'top-down' methodology where tree canopies took precedent over other classes. This means that any tree canopy area that intersects with building footprints can be assumed to be overhanging that structure's roof. Each building footprint polygon in the study area was populated with a value corresponding to the percentage of the rooftop free from this shading. These values could then be used in the calculation of usable roof area when determining the total solar radiation for a building. Considerations were not made for the impact of tree species and differences in leaf volume over a year. Therefore, this value relates to the tree canopy area at the time the imagery was recorded.

Similar to the drawback with how the solar data rasters are calculated and represented, using building footprints assumes a planimetric roof structure. This can result in the underestimation of the total roof area by under-calculating the surface area of pitched roof faces and excluding any roof overhang in the calculation. A resolution to this issue would require the use of a three-dimensional solar model and building geometry, both of which are not available for this study and would increase the cost and technical requirements of reproducing this workflow. A review of other web applications and solar radiation modeling studies found that assuming a planimetric rooftop is not uncommon, but further research is required to determine the impact it has on the results (Dean et al, 2009; Agugiaro, 2012); .

3.4.4.2 Land Cover

The land cover data obtained from the Toronto Urban Forestry Inventory is used to investigate the proportions of land cover types in neighbourhoods and individual property parcels. This enables users to investigate the relationship between land cover types and surface temperature, as well as develop a greater understanding of the distribution of tree canopy and green areas in the city. While properties such as surface albedo may provide a more objective comparison to temperature, it is less intuitive and does not necessarily provide an immediate, real-world connection for the user.

The land cover data, initially available in raster format at a spatial resolution of 0.6 metres was aggregated to polygons of property parcels and neighbourhoods in Toronto, where each class was represented as a percentage of the whole polygon. Using a percentage value rather than an areal measurement such as square metres makes the values simpler to investigate as it is immediately evident how neighbourhoods or parcels compare. While the aggregation of raster data eliminates spatial detail of all land cover classes, it permits areal calculations to be pre-processed for every polygon. This greatly reduces the real-time spatial analysis demand on the server when users are comparing proportions of land cover classes in an area. This makes the data accessible through an attribute query rather than a server-side geoprocessing task that must perform these calculations on-demand.

3.4.4.3 Surface Temperature

Surface temperature is a useful factor to analyze when investigating land cover features that contribute to UHI as it closely relates to albedo (Taha, 1997). Investigating the relationship between surface temperature and land cover can shed light on how the urban environment might be altered to alleviate issues related to UHI. One example of this is the potential increase in tree canopy cover called for by projects such as the Green Development Standard or Toronto's Every Tree Counts program (City of Toronto, 2010, City of Toronto, 2012b). Increased tree canopy cover mitigates the effects of UHI increasing surface shade, which reduces the need for cooling and providing a carbon sink for the urban environment (Solecki et al., 2005). It also improves evapotranspiration, which in some cases may play a larger role in reducing UHI than shading itself (McPherson et al., 1994).

Surface thermal data recorded from Landsat ETM sensors were calibrated and converted to degrees Celsius through the method described Section 3.2.3. These data layers were visualised as continuous rasters that were clipped to the City of Toronto's boundaries. Visualising surface temperature data in an intuitive manner possesses a number of challenges due to temperature variance over time and the necessity to overlay the data on different base maps and with other map layers. Both of these issues can be mitigated through the use of careful colour representation, the ability for users to dynamically alter visibility of the overlay, and the inclusion of different data formats.

Each surface temperature raster was represented using a red-to-green dichromatic colour gradient. This intuitively relates red areas with hotter surface temperatures and green areas with cooler temperatures. In addition, temperature ranges are normalized for all six days making it easier for users visually identify the change in surface temperature between rasters. Mitigating issues with colour confusion between these overlays and the base map was done by allowing the user to adjust layer transparency dynamically. This decision was made as the wide variety of colours and textures used in both base maps can conflict with different colour options in different parts of the study area.

The date and time for when each year's data are captured can be mostly controlled due to the regular flight pattern of the Landsat satellites. They follow a 16 day cycle, being at nadir with Toronto at around 10:00am local time. However, weather conditions can vary considerably from day to day and between years. In addition, the calibration process for the data did not account for variations in atmospheric transmissivity. These factors affect overall surface temperature measurements, making it impossible to objectively compare changes in surface temperature over time without calibration and normalization. This is alleviated by reclassifying the data as temperature values above and below the mean temperature for the scene. This distinguishes regions of the study area that are warmer or colder than average for that day, regardless of the overall temperature. While this does not eliminate the problem as the overall temperature range can vary, it improves how well the data can be compared visually. Both the calibrated and averaged surface temperature visualisation options are shown in Figure 3.16.

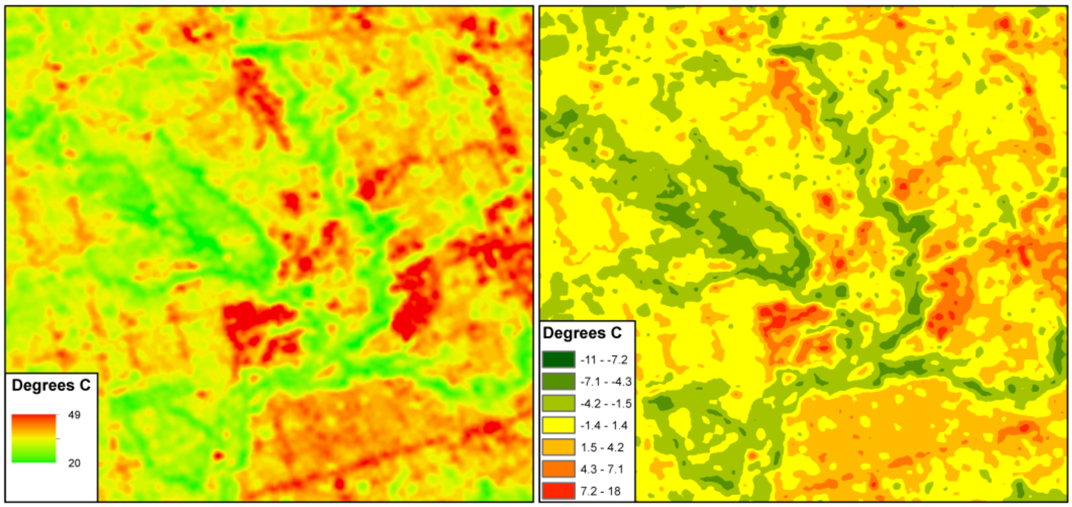


Figure 3.16: (a) Calibrated temperature and (b) averaged surface temperature

Another challenge in visualising remotely sensed data for non-experts is the representation of radiometric responses as square pixels. Cracknell (1998) provides an excellent discussion on the numerous challenges of representing remotely sensed data in raster format including ‘mixed pixels’, point spread function (PSF), and resampling of data to name a few. The issue of ‘mixed pixels’ is the representation of non-homogenous areas as rectangles. A single 60x60m Landsat ETM thermal pixel may include a combination of high and low emissivity features, but some may contribute to the signal more than others, resulting in a pixel that is predominantly one response. PSF is the response of a sensor to a point source of a signal within the instantaneous field of view. Sensor noise and inability to resolve and represent sub-pixel details can result in a value disproportional to the signal’s presence in the area. The centre of each pixel area typically contributes more to the signal than the periphery. Orthorectification of satellite imagery is a common process that resamples a raster, altering the geometric area of the scene. This forces a change in the sub-pixel shape of the data, which cannot be represented by a raster. This is rectified using an interpolation technique such as bilinear, bicubic, or nearest neighbour. The selection of this technique can impact the validity of the data at near-pixel or sub-pixel scales.

Resolving these and other remote sensing visualisation issues is a significant challenge that is not touched upon in this research. Being aware of their impact on measurement validity and data visualisation can lead experts to be naturally skeptical. Preventing non-experts from making false assumptions about data validity is difficult. It can be mitigated by carefully considering how data are visualised and at what detail levels it is available for. For this reason, temperature values in degrees Celsius are not made available and cannot be investigated for individual pixels. In addition, the surface temperature layers were interpolated using the bilinear method, which uses a weighted average of surrounding pixels when determining the new value. This is ideal for continuous data such as surface temperature, and mitigates the misrepresentation of significant temperature values being shifted over different land cover (ESRI, 2012e).

3.4.4.4 Publication of Data to ArcGIS Server

Once each dataset has been generated, individual rasters and feature classes were added to ArcGIS map documents. The data to be used for visualisation purposes were ordered, symbolised, and optimised for publication to the ArcGIS Server. Data used to support functionality but not meant to be visible to the user were added to a map document that was then published as a map service. Map services can be used as a source for visual data by referencing the map service as a dynamic or static map service layer or as a feature layer. Attribute data for the layers in a map service can be accessed using a query task as described by the API (ESRI, 2012f).

Additional functionality such as geocoding addresses or performing spatial queries require additional components to be published to the ArcGIS server. To geocode addresses, an address locator must be developed using address points or a numbered street network. The locator is then published as a geocode service, which can be used by a web application to geocode addresses based on the linked data. A geometry service is simply exposed as a published service by ArcGIS server to extend geospatial analytical functionality to a web application.

Three map services were published to ArcGIS Server on a locally administered computer running Windows Server 2008. The first map service contained data layers for visualising the clipped and unclipped versions of solar insolation as well as sun duration hours for both study areas. The second map service contained 12 surface temperature layers, two for each of the six periods of time available. These include the rasters representing surface temperature in degrees Celsius and those representing deviations from the mean temperature. The third map service consists of all minor data layers and non-visual components. This includes the study area boundaries, a tree canopy layer, building footprints with solar resource data, and a neighbourhood boundaries layer.

A geocoding service was developed using individual address points obtained from the Toronto Open Data website. This service was calibrated for querying numbered addresses only in Toronto. Existing geocoding services that are available from ArcGIS Online were tested but commonly missed addresses in the study area. Providing a false positive result that navigated the map view to a different city would potentially confuse the user. A geoprocessing task was also published that enabled the Solar Calculator widget to submit geometry to the server. This geoprocessing task calculated the total solar radiation for a given year within that area and returned this value to SunSpot.

3.4.5 Application Component Design

The design choices made for each component in SunSpot were based on balancing ease-of-use and intuitiveness with functionality. Too many tools and functions can result in an application with an overly complicated interface and a considerably steeper learning curve. This can limit the audience to only experts. This section describes the design of each software component of SunSpot including the design and behaviour of the interface and the technical design of each tool and widget. The rationale behind the choices made are also described.

3.4.5.1 Data Layers and Base Maps

Data visualisation plays an important role in the communication of spatial information, especially to non-experts who are unfamiliar with existing cartographic conventions. SunSpot was built with two base maps as well as a number of overlays including annual insolation, annual sun hours, surface temperatures for a selection of dates, and tree canopy cover. The ESRI Online World Topographic Base Map was used as a reference for topography, streets, buildings, addresses, and basic land cover features such as trees and parkland (ESRI, 2012g). The Bing Maps Aerial World Base Map was used as a visual reference for surface features including land cover and buildings. These layers were included as they let users visually investigate the data separately from the workflows associated with each widget. It also gives users the freedom to compare any of these layers with data or visual components from the widgets. Layers that display neighbourhood boundaries, property parcels, selected buildings, and drawn geometry are set to only be visible at specific stages of each widget's workflow.

The dynamic nature of Web-based maps presents a cartographic design challenge. Properties such as layer order, visibility, symbology and scale levels can all change based on user-input and are not restricted to a finite number of combinations. Unlike traditional paper maps, considerations must be made for how each map element is represented and what control the user has over their display (Veregin, 2011). It is important to let the user investigate these layers as freely as possible while mitigating the possibility of user confusion or over-restriction of visualisation capabilities. Through investigation of existing web-applications that are visually and interactively effective as well as research on best cartographic practices, a number of key concepts were identified for consideration when developing the data layers and layer interface (TYDAC, 2004; Van den Worm, 2000; Veregin, 2011; City of Boston, 2012; City of New York, 2012).

The first concept is to ensure that layer symbology intuitively communicates the data but is also complementary to other layers that might be simultaneously visible. For example, vegetation is best identified as a shade of green, but the selected colour should contrast from the colours found in the base maps so that it is easily distinguishable. The second concept is to govern which layers can be made visible at any time and which are only visible at specific stages of the workflow. This mitigates potential user confusion and directs focus to the visual components relevant to the current workflow. The third concept is to control which layers can be visible in conjunction with each other. This is accomplished by determining which map layers may commonly be used together and which can be designed to be exclusive of each other. The last concept is that layer controls should be designed in a way that these restrictions are intuitive to the user in order to minimize confusion. This also passively communicates the relationship that exists between layers.

The solar potential rasters were symbolised using a red-to-blue dichromatic colour ramp that contrasts between high and low insolation values. Clipped versions of both the yearly insolation and annual sun hour rasters were produced, showing only rooftop areas. The unclipped rasters give users the freedom to investigate solar potential and the effects of local shading on non-rooftop surfaces. The clipped rasters display the minimum amount of data necessary for rooftop investigation, making the map easier to navigate and helps the user retain visual reference of place. The difference between clipped and unclipped solar rasters and the colour gradient employed is evident in Figure 3.17.

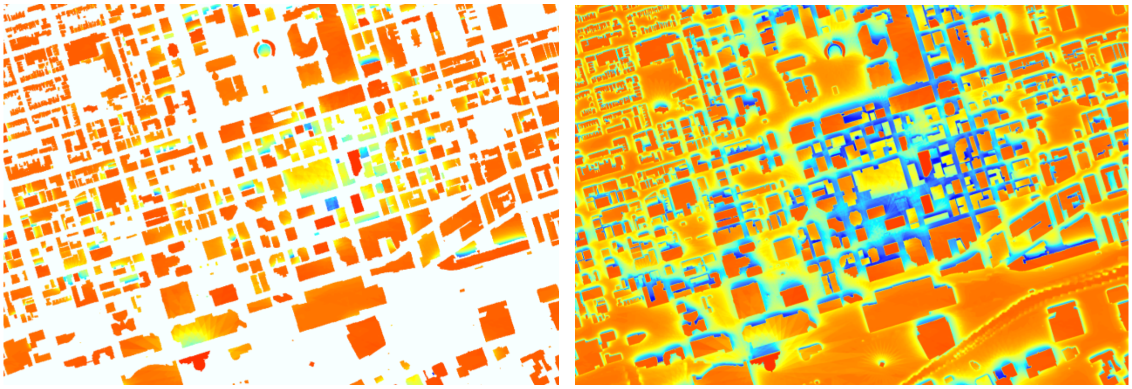


Figure 3.17: Example (a) clipped and (b) unclipped solar layers

As described in section 3.2.4, the calibrated surface temperature data layers were adjusted to represent temperature in degrees Celsius above or below the average. This was done to improve the ability for the data to be compared across time despite varying conditions that affect surface temperature. These breaks are visualised in classes reflecting temperatures within one standard deviation, which is represented by beige, as well as two and three standard deviations above and below of the mean represented in different shades of red and green respectively. The data are then spatially interpolated using an on-the-fly bilinear interpolation technique. While this increases radiometric uncertainty between pixels, it serves dampen sharp breaks between cells, which are counter-intuitive to what the user expects to see for surface temperature. Describing the details behind this technical issue would require the introduction of additional concepts, which is counter to the objective of making the application simple and intuitive for non-experts. The difference between interpolated and non-interpolated data are displayed in Figure 3.18.

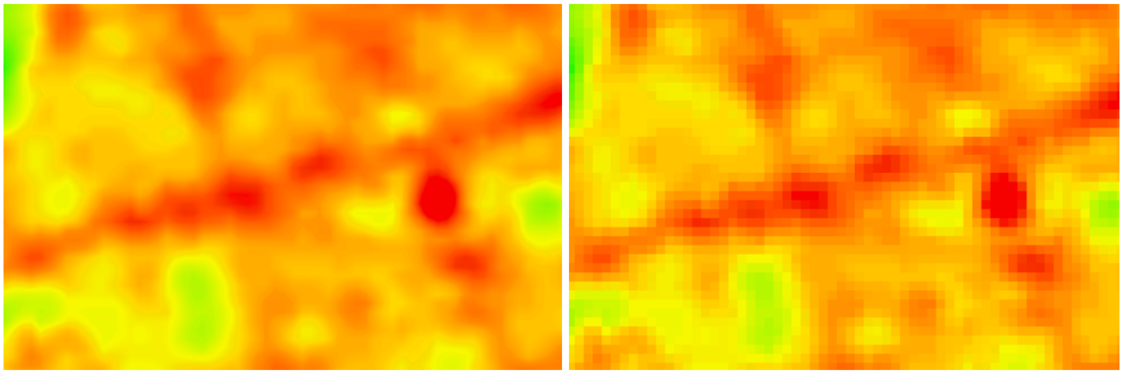


Figure 3.18: Surface temperature layer (a) with and (b) without bilinear interpolation

Tree canopy data was extracted from the previously described land cover data and displayed as a discontinuous raster that can be displayed on top of any existing layer. Represented in dark green, the colour does not interfere with the symbology of any other layer that can be visible at the same time. Unlike the other layers, the transparency level of the tree canopy layer cannot be changed. An example of the appearance of tree canopy data overlaid with the topographic base map is provided in Figure 3.19.

Figure 3.19: Tree canopy overlaid on the topographic basemap

3.4.5.2 Layer Interface Module

The interface for showing and hiding these layers was designed as an anchored menu that appears when one of two buttons labelled "Solar" and "Thermal" are clicked. This sectioning of the tool served two purposes. First, it created two distinct themes where functionality found inside each are related to solar or thermal data. Second, it minimizes the interface footprint by requiring screen space for only one of the two menus at any time. Each section contains a list of layers in the form of radio buttons, permitting only one layer to be active at a time. This was designed to simplify the user interaction with the layers as well as prevent cases where multiple layers are visible at once, which is not visually advantageous when displaying rasters. The solar layer also contains checkboxes that toggle the tree canopy and study area boundary overlays. This was included to let users easily visualise where trees are potentially obstructing rooftops. Both menus also include common elements including a button to toggle the legend and a transparency slider. Letting the user adjust transparency was necessary as both base maps vary in composition and colour, making some features difficult to see at one set transparency level. Figure 3.20 shows both later interface menus.

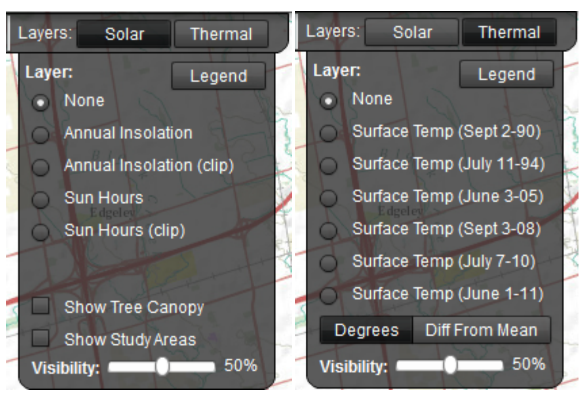


Figure 3.20: (a) List of solar layers, study area and tree canopy and (b) thermal layers

3.4.5.3 Solar Calculator Widget

The Solar Calculator is a widget that is designed to assist users in determining the feasibility of rooftop PV power generation. This is done by calculating estimated revenue as well as carbon savings based on either pre-processed or dynamic solar values, obtained from the solar potential data described earlier in the chapter. Once opened, the Solar Calculator has two potential work flows that the user may follow, both of which are described in the flow chart in Figure 3.21.

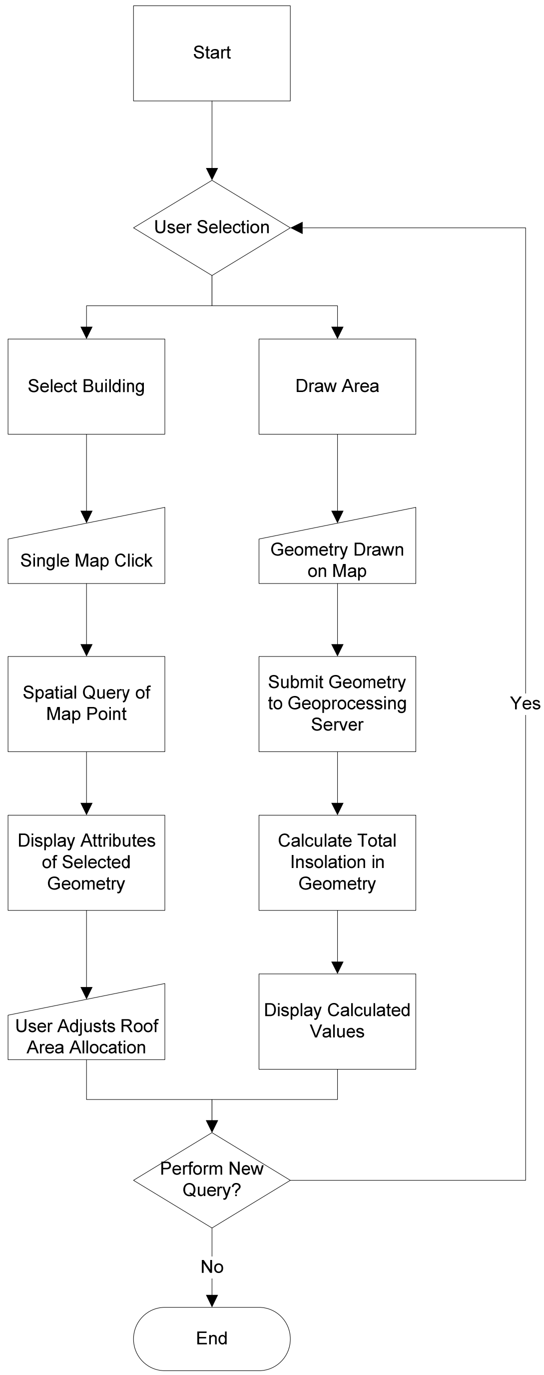


Figure 3.21: User work flow of the Solar Calculator widget

Selecting a building is done by clicking the “select building” button and clicking on a rooftop in the study area. A number of values are returned, including the closest geocoded address for that building, building height, data source for the height, planimetric roof area, and average yearly roof insolation. Using the roof area and roof insolation, the estimated FIT rating is calculated and displayed. In addition, an area chart is populated with monthly insolation trends in comparison to the study area average. The user can then adjust a slider for how much roof area to commit to PV panels, observing the real-time change in allocated area in square metres, estimated annual revenue, FIT rating, and estimated carbon savings.

Drawing a custom area for PV panel placement is done by clicking the “draw area” button and drawing a polygon directly on the map by clicking to create vertices. The completed geometry is uploaded to a geoprocessing task on the server, which calculates and returns the total radiation for the area. This value, as well as the area in square metres is used to determine the FIT rating, estimated annual revenue, and estimated carbon savings. While the draw area method is more server-intensive, leading to longer processing times of three to five seconds, it permits the user to freely investigate the potential any area on or off a rooftop. Furthermore, it lets a user choose only specific parts of a rooftop, which is an advantage over the ‘select building’ method. This lets the user investigate how rooftop solar potential can change among roof faces due to area, aspect, and slope. Since the ‘select building’ method returns averages for the entire building, it does not necessarily reflect using the most ideal portions of the roof to use. The final design of the solar calculator widget including the ‘select building’ and ‘results’ tab are shown in Figure 3.22.

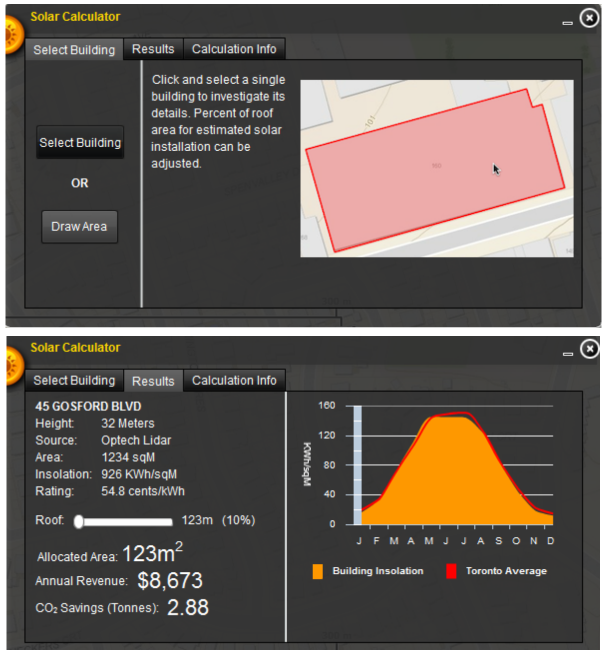


Figure 3.22: Select building and results tabs of Solar Calculator

The FIT rating for a selection is based on the area of the selected or drawn polygon. This area value in square metres is determined either as a pre-calculated value for building footprints or as a returned value from the geoprocessing service. A subroutine on the client-side compares the areal value to the FIT and MicroFIT list of rates based on area ranges described in Chapter 2. This value, along with the area is used as a part of the calculation for both the estimated annual revenue and estimated carbon offset.

The estimated annual revenue is calculated using a formula that identifies the actual estimated solar radiation potential and multiplies it by the FIT rating. This formula accounts for the selected proportion of building area, a derating factor for DC to AC conversion loss, and typical solar panel efficiency. Assuming that:

r = revenue estimate in $CAD per year
p = user-selected roof percentage use between 0 and 100,
a = polygon area in square metres,
i = average insolation value for the selected area in kWh/m^2*,*

d = de-rating factor between 0.0 and 1.0,
e = solar panel efficiency factor between 0.0 and 1.0, and
f = FIT rate in cents per kWh

the formula is as follows:

$$r = a \frac{p}{100} i \, d \, e \frac{f}{100} \tag{3.1}$$

For this study the derating factor was set to 0.77, which was based on the value used by PVWATTS, a Web-based solar feasibility calculator (Marion et al., 2001). The solar panel efficiency was set at 0.18, which was a compromise between the efficiency of current commercially available solar cells and those in development (Green et al., 2012; SroEco, 2012). These values can be adjusted as necessary or tied to specific PV installation options in the future, but were used to generate reasonable calculations for this study.

The estimated carbon offset is a similar calculation where the estimated total energy in kWh generated is multiplied by a value representing the average carbon offset in tonnes per kWh. The value of 0.000182 tonnes of carbon per kWh was obtained from the RETScreen International clean energy analysis tool developed by Natural Resources Canada in October, 2012 (Thevenard et al., 2000). Assuming that:

c = carbon offset estimate in tonnes per year

s = average carbon offset in tonnes per kWh

the formula is as follows:

$$c = a \frac{p}{100} i \, d \, e \, s \tag{3.2}$$

3.4.5.4 Land Cover Widget

The Land Cover Chart widget lets users select a neighbourhood or individual property parcel and view a pie chart displaying the proportion of each land cover type in the selected geometry. As described in Section 3.2.3, the data were aggregated from raster format to attribute data for each parcel and neighbourhood polygon. The Land Cover Chart widget was designed to automatically change between displaying data for neighbourhoods or parcels depending on the zoom scale of the base map. This choice was made as the usefulness of these features depends on the map scale. At the level where individual parcels are visible, a single neighbourhood consumes the entire map viewframe. This reduces the number of controls required on the interface and simplifies the work flow for the user with a near-zero loss to functionality.

Colour choice for the layers follows an intuitive theme where vegetation classes are green, hard surfaces are grey, water is blue, bare earth is yellow, and buildings are red. A pie chart was selected above other chart options as it intuitively contrasts the proportions of various classes such as vegetation versus hard surfaces and buildings. The chart was also configured to always group vegetation classes as well as hard surface classes together so that they are more easily visually aggregated if desired. The land cover widget interface and example pie chart result are seen in Figure 3.23.

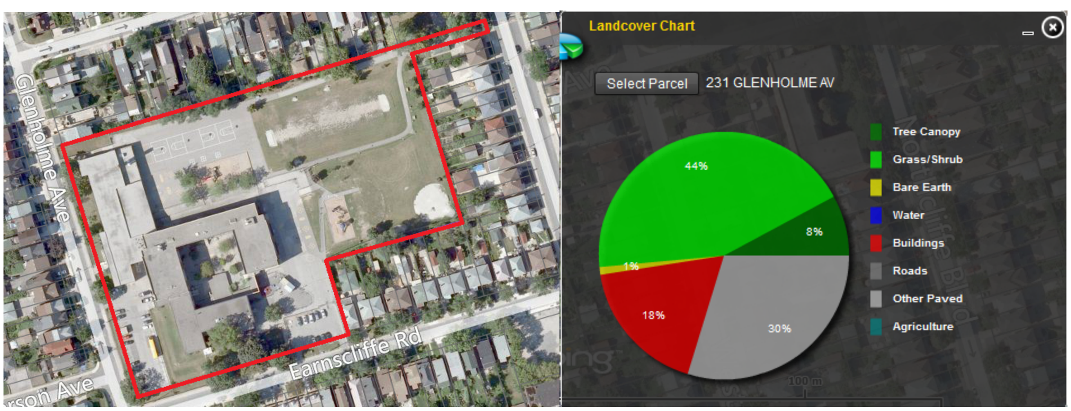


Figure 3.23: (a) Selected property parcel and (b) resulting land cover chart display

3.4.5.5 Thermal Transect Widget

The Thermal Transect widget lets users to investigate how surface temperature changes across an area. The widget is built on the publicly available Elevation Profile widget by Mark Deaton that was obtained through the ESRI ArcGIS Server for Flex website (Deaton, 2012). Users can draw a profile line that is submitted to an 'elevation profile' service on the server. This service treats the temperature variations as if they were changes in elevation across the transect. The data are returned and displayed as a graph, which shows the variance in surface temperature across the transect. The graph appears in an automatically generated pop-up window that can be moved and closed by the user, ensuring that it is not obstructive. The colour scheme used by the chart is the same dichromatic red-to-green gradient used by the surface temperature data layers. This conveys to the user that these values are coming from the same surface temperature data as displayed.

The widget has been modified to support thermal as opposed to topographical data and allows the user to select which surface temperature data source to use for each profile. Users can investigate the thermal transect by moving the mouse across the graph, which displays temperature values in a tooltip as well as places a reference point that moves along the transect line. The surface temperature data layer used for the transect is selected by the user changing the selected time in a dropdown list. This is separated from the display of surface temperature layers so that the user may draw a thermal transect over other data such as thermal layers from different years. The thermal transect widget interface and an example of the resulting profile graph are seen in Figure 3.24.

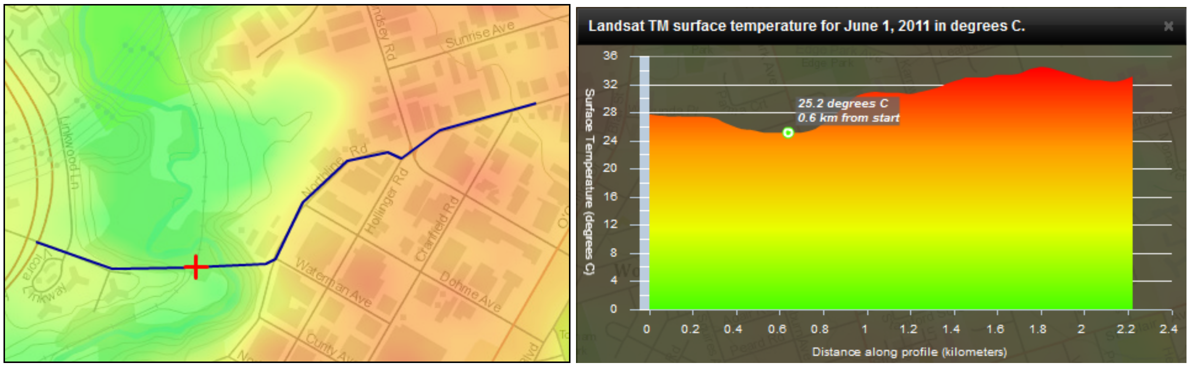


Figure 3.24: (a) Example drawn transect line (b) example transect chart as a result

3.5 Summary

This chapter described the methodology behind the design of Solar Analyst and the datasets that support its functions. It identified Toronto as a case study for testing solar resource data development and publication using a Web-SDSS. In Toronto, two smaller areas were used for solar resource data development due to the availability of two different topographic data sources. The methodology for generating and using DSMs to develop solar resource data was described. Finally, SunSpot was introduced with detail on functionality and data requirements as well as the design of each component that makes up the Web application. The next chapter discusses the design of a script-based in-person workshop used to test SunSpot.

Chapter 4 – Research Design

An in-person workshop exercise was developed that tested the usability of the various tools and spatial data products made available through SunSpot. Individuals followed a written script that guided their use of the application and solicited feedback through a written survey. This, along with participant observations provided useful information on how SunSpot performed and what possible improvements could be made for future versions of this or other applications.

This chapter describes how the workshop was designed and conducted. Section 4.1 describes the purpose of the workshop along with the rationale for why it was selected as a method for testing SunSpot. Section 4.2 lays out the design of the workshop script and describes how it was structured. Section 4.3 describes what types of individuals were sought for participation and how they were selected. Section 4.4 discusses the types of survey questions asked, how they were administered, and how they help gauge the success of SunSpot. Information on the logistics of the workshop sessions including location, time, and program schedule are detailed in section 4.5. The chapter is summarised in section 4.6

4.1 Purpose of Workshop

In fulfillment of two of the research questions introduced in Chapter One, the purpose of this workshop was twofold. The first objective was to test SunSpot's effectiveness in communicating local level climate change issues and assisting different user groups in associated decision making processes. The second objective was centred on identifying recommendations for future improvement of SunSpot and similar Web-SDSS applications. As an added result of this exercise, the application was also tested for technical issues that may have been overlooked during internal testing. These objectives were met through a series of in-person workshops that guided participants through the use of SunSpot in order to observe activity as well as solicit written feedback. Participant feedback was shaped through the careful design of a questionnaire that sought both to investigate SunSpot's usability from participants' perspectives and to provide a medium for communicating identified problems and needed features that might be satisfied in later development.

4.1.1 Usability Engineering

Usability is the measure of how well an application fits the needs of its intended audience and how well it enables them to complete desired tasks (Landauer, 1995). Usability engineering (UE) investigates the development of common practices that optimise an application's usability. These practices involve recurring themes and design principles that have been shown in previous work to be effective in addressing the usability of an application (Butler, 1996). Haklay and Zafiri (2008) reference one list of concepts using the 'five E's' of UE: efficient, engaging, effective, error tolerant, and easy to learn. The authors believe that UE for GIS is becoming increasingly important, where elements such as these require careful consideration when designing applications to meet user needs.

Research has been conducted on how UE applies to Web-GIS development with many authors discussing how compatible traditional methods are in this context. UE is considered to be of great importance due to the interactive nature of Web-GIS and other geovisualisation applications (Tobon, 2002; Schmiguel et al., 2004; Haklay and Zafiri, 2008). In addition to efficiency and engaging (described as 'interactivity'), Sidlar and Rinner (2006) identified additional issues to be evaluated that are unique to web-based applications, including cost of entry and Internet connectivity. Cost of entry is with regard to potential barriers such as software requirements on both the server and client side that may impede users to be able to access the application, or authors from keeping it available. Connectivity, such as bandwidth, latency and persistence of connection between the client and the server can impact accessibility of some Web-GIS applications, such as those designed for consistent bi-directional data flow or to share large volumes of data.

In addition to testing the technical components that relate to usability, it is also important to investigate how well users understand and value the data and results obtained from using the application. This is either considered as a by-product of UE testing and therefore investigated as a component of user satisfaction and memorability, or investigated separately by explicitly testing for knowledge and understanding developed by the user (Koua et al., 2006; Sidlar and Rinner, 2006). These authors used numerical scales to poll participants on their satisfaction and understanding of results. In cases where the results are more complex, further investigation including in-person observations, discussion of the results, and written discussion on user perceptions is important.

In measuring the success of UE, a number of authors consider many traditional methodologies to be ill-suited to Web-GIS and geovisualisation. The nature of GIS and, in particular, SDSS involves the exploration of problems that are often ill-defined in scope and methodology (Keim, 2001). The application's function is often directed at exploratory tasks or the investigation of dynamic issues where the user acts as a supplier of data or expertise (Andrienko and Andrienko, 2006; Tobon, 2005). Many UE methods test the 'five E's' in a manner that does not assume an open-ended use. For example, performance testing observes how long users take to complete a specified task, providing an objective measure of efficiency (Dumas and Redish, 1999). Geovisualisation applications often offer numerous possible workflows for users to analyse and investigate intermediate results, make adjustments, and test different inputs or assumptions. Attempting to gauge usability of these tasks by measuring the time it takes to complete them would therefore be meaningless.

There are a number of ways to test geospatial applications that authors have shown to be effective. Usability testing is one of the most common methods where participants interact with the application while actions and observations are recorded (Dix et al., 2004). Recording can be done in a number of ways including in-person observation by facilitators, software data capture of interactions, or video recording of the computer screen and, in some cases the participant (Lin et al., 1997). In-person observations provide a holistic sample of HCI as the facilitator can observe both the screen and user interactions in real-time, including observing body language and possible discussions between the user and facilitator. Video recording of sessions provides similar capabilities, but is lossless compared to human memory and permits many more participants to operate simultaneously. However, this requires more planning, additional costs for technology, and more time-consuming data analysis. The use of eye tracking in UE has been relatively new in the past few decades, becoming more popular as technology capabilities and costs improve. Coltekin et al. (2009) used an eye tracking apparatus to measure the visual movement and focus of participants as they conducted a number of simple tasks on two online map interfaces. Their results found that in combination with other data gathering methods, eye tracking enhanced the usability studies. Software recording of interactions can help reproduce part or all of each user session, allowing facilitators to build reports on how specific UI elements are interacted with, processing times for tasks, and easily identify and reproduce errors (Lin et al., 1997).

The use of questionnaires, often as a supplementary component to usability testing, is also a common method for obtaining feedback. Questions can be formulated to investigate any objective or subjective issues that the user could respond to at any point in the application's development process (Babbie, 2006). While some questionnaires may be included in, or follow usability testing, others can be used to reach a much broader audience in an affordable manner, especially if the application is Web-based (Haklay and Zafiri, 2008). Questionnaires are also an ideal way to quantify user satisfaction with various components of an application, which is an important component of measuring usability (Chien et al. 1988).

4.1.2 Testing SunSpot's Usability

An in-person workshop was selected as the optimal format for initial tests of SunSpot. While SunSpot is a Web-based tool and could immediately be accessed by participants remotely, an in-person workshop helps ensure that the testing methodology is effective before exposing the workshop to a wider audience. This provided the greatest flexibility of interaction with the participants as any potential roadblocks in testing would be quickly identified and alleviated. In this sense, an in-person workshop also helped identify how effective the workshop is in exposing participants to all components of the application and soliciting valuable feedback. This lays the groundwork for possible future testing that may take advantage of a wider audience. A substantially larger test group from online testing may provide little useful feedback if the workshop design or application itself has critical errors that inhibit use.

The in-person workshop provided an opportunity for personal interaction, which allowed additional feedback to be gained through informal discussions as well as brief ‘over-the-shoulder’ observations. Discussing different components of the application with users allowed valuable data to be collected that may not easily be expressed through other forms of response, such as the strength of opinions regarding certain components. It also provided an opportunity for open-ended discussions about parts of, or the whole application that may not be possible through written responses. Observing how participants performed tasks in real-time helped identify issues that may not have been considered when designing the written survey. Not only did this shed light on further issues to consider, but it helped shape the informal discussions that took place during and after the workshop. By combining different methods of data gathering, confidence in the results could be improved. Known as triangulation or cross-examination, this method increased the data points gathered while mitigating potential bias introduced from using a single technique (Creswell, 2008).

During the design of SunSpot, a module was developed that would record all user interactions with the application. This module allowed each mouse click along with screen coordinates and time to be recorded. In addition, the manipulation of all tools including changing the map view, toggling visual layers, opening and closing widgets as well as executing widget workflows would be recorded. As SunSpot has no stochastic components, these data would be sufficient to allow sequential playback of a user’s session and the ability to ‘step-through’ each action at any pace. While part of this tool was designed and programmed, completion of it was abandoned due to increasing complexity and time constraints. Such a tool, while providing highly detailed observational data, would require substantial testing to ensure that the recorded observations are accurate.

4.2 Workshop Exercise Script

The exercises conducted in the workshop were structured by using a written script that guided participants through a number of tasks that were intended to simulate how they would likely use the software if it was available online. The use of a script ensured that all participants completed the same tasks so that results could be compared and that common issues were identified. It also allowed emphasis to be placed on testing certain components by including more detailed tasks. Time constraints were also a concern as individuals may find certain application components to be of more interest than others, resulting in incomplete testing of SunSpot. A script helped minimize this by encouraging participants to complete only the assigned tasks rather than freely investigating the components of greatest personal interest.

The workshop script was designed to be semi-structured, balancing the guidance and simplicity of a linear workflow of tasks with the freedom in some cases of deciding where in the study area to perform a task. Tasks were divided into different sections based on which widget or module was being investigated. While many components of SunSpot were designed to be used in any order or combination, this division helped keep focus on the elements being investigated. Each section was structured by combining text and graphical elements to identify the tools being described (Figure 4.1). More complex components were displayed with text references to each component (Figure 4.2). In some cases, specific locations and examples were used in order to take advantage of more evident examples of differences in data, while in others the locations were only suggested in case the user was not familiar with any other suitable place in the study area.

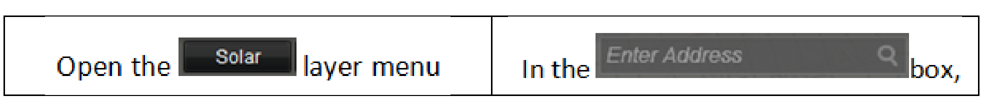


Figure 4.1: Workshop Script example of text and graphic elements

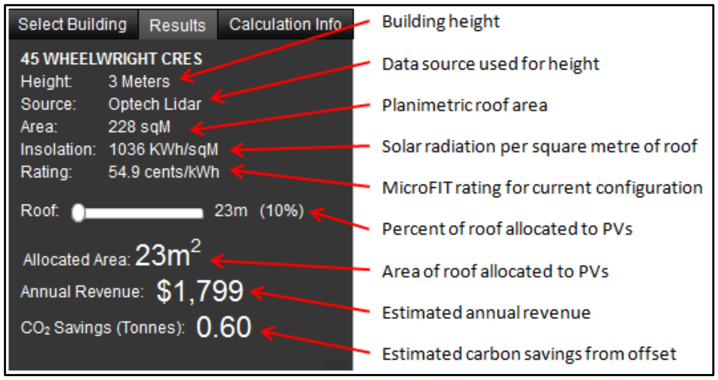


Figure 4.2: Workshop script example of text-described elements

The following subsections in this chapter describe the objectives and design of each section in the workshop script. The order of these subsections corresponds with the order of the sections in the script, which is reproduced as Appendix A. Section 4.2.1 describes the introduction section where participants are made familiar with the basic UI and navigation tools. This serves as a bridge for those without previous web mapping experience, ensuring that participants of all skill levels are built up to the required level of expertise to complete the workshop. Section 4.2.2 introduces land cover and surface temperature layer data, first by showing how to display various datasets, then by introducing the Land Cover Chart and Thermal Transect widgets. Section 4.2.3 introduces solar resource data and solar potential calculations. In this section, two tasks are completed where participants calculate a number of solar potential metrics by selecting individual buildings as well as drawing custom areas on specific building footprints. A fourth section in the workshop script that contains only survey questions is discussed in greater detail in Section 4.4 of this chapter.

4.2.1 Familiarization with the User Interface and Navigation Tools

The first section of the workshop script was designed to familiarize the participant with SunSpot's user interface and available data layers. This was done to help the user become acquainted with the application and the study area by navigating to different neighbourhoods and zooming between different scales. The participant was also made aware of both available base maps and how to toggle between them, as it is not always explicitly suggested which base map is ideal during later parts of the exercise. The Find Address tool was also used, assuring that the user is familiar with querying addresses, which is done numerous times in the later sections. The section is short and relatively open-ended as the expectation is that most users were already familiar with how to navigate a Web-map and search for addresses.

4.2.2 Investigating Land Cover and Surface Temperature

Section Two guided participants through the use of the Land Cover Chart widget, an introduction to the available surface temperature layers and visualisation options, and the use of the Thermal Transect widget. Investigation of these components was combined into one section as they were designed to be used in collaboration. Nevertheless, each can be used independently and therefore the script was divided into three subsections. This makes the separation between components and workflows evident and provides an opportunity to include survey questions about individual components.

This section was designed to test the complexity of using both widgets and understanding the surface temperature visualisation methods. By having participants follow a procedure that demonstrated how each widget is used, questions could be asked that inquire about their perceptions on ease of use, usefulness, and any suggestions on improvement. Participants were instructed on what the visualisation methods depicted and were given an opportunity to compare how each behaved in the same geographical area. This enabled observations to be made about usability and understanding as well as enable participants to comment on these visualisation options.

The first part investigated the land cover data through use of the Land Cover widget. A brief introduction displayed the widget and discusses its functionality. An example was provided of how the widget's behaviour automatically changed based on map scale level, allowing the user to investigate property parcels or neighbourhoods. Users were then instructed to select a number of neighbourhoods and property parcels, observing how the pie chart would change to reflect the land cover of that area. This exercise helped make the intended use and behaviour of the tool evident.

The second part of this section investigated the available surface temperature map layers. A description of the surface temperature data was provided, which briefly explained how it was obtained and what it displays. The difference between the two visualisation methods which showed basic temperature values or difference in temperature from the mean was also explained. The user was then walked through using the Layer tool to toggle between surface temperature layers from different dates as well as between the two visualisation methods. They were also instructed to investigate how surface temperature could be used in conjunction with the aerial imagery basemap to identify any relationship between visual land cover and temperature. This section also served to introduce and provide experience with the Layer tool that will be used with the Solar Calculator in the third section. Introducing this component at this stage of the workshop reduced the number of new concepts being introduced later.

The third part guided the participant through the use of the Thermal Transect widget. The participant navigated to a specific address and drew a transect line that follows an example walking path as described in the script. The path used was selected as it moved from a trail with tree canopy cover to an open street. It helped display how the transect could be used to visualise and investigate how temperature may change due to land cover changes along a route. By using a walking path, the participant may be able to identify with their own experience of moving from a covered, vegetated area into an open street on a warm day. The example walking path and resulting graph is displayed in Figure 4.3.

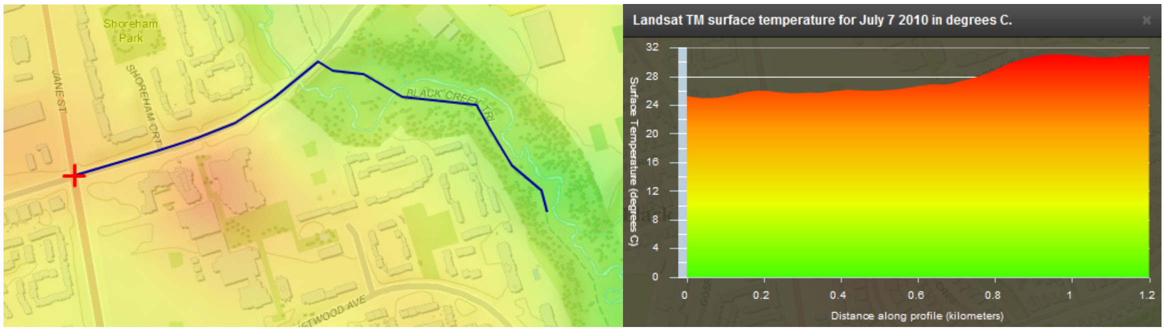


Figure 4.3: Example drawn thermal transect and output graph

4.2.3 Investigating Solar Resource Data and Potential

Section Three of the script introduced the participant to the solar resource data layers and the Solar Calculator widget. While this section dealt with the core component of SunSpot, it was left to the end of the script as the concepts are relatively complex and in some cases relied on the use of previous tools. By this point, participants were likely more comfortable with navigating the map, searching for addresses and panning to neighbourhoods. They also had experience with toggling between visible layers and adjusting layer transparency.

This section was designed to test if participants understood the results provided by the Solar Calculator widget and, more specifically, the difference between the two methods available. By having participants generate results for both methods, it was possible to investigate if users understood the benefits and drawbacks of each, identify any preferences, and solicit opinions or other thoughts on how they might be improved. Results including solar potential, savings estimates and carbon offset estimates were also investigated by asking about the ability to interpret results.

The first part guided the participant through the layer options available for displaying annual insolation or sunlight hours, both as continuous rasters and rasters that cover only rooftops. After this, it was up to the participant to choose which visualisation method to use for the remaining steps. The tree canopy overlay was introduced, allowing users to display where tree canopy covers rooftops. The participant was guided to a specific address where nearby buildings provided ideal examples of how roof topography could impact insolation (Figure 4.4).

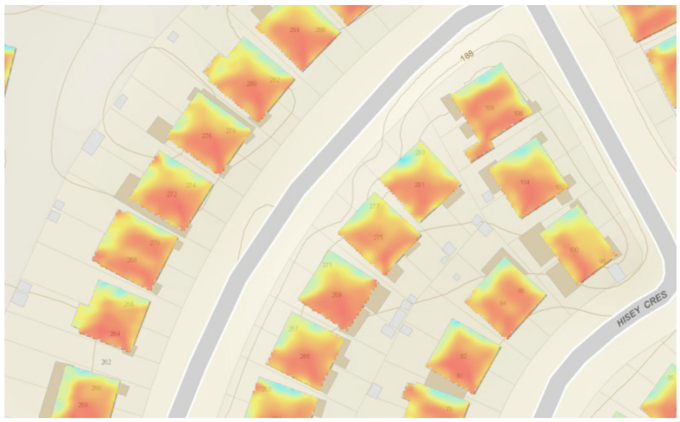


Figure 4.4: Example area used to show potential use of solar resource layers

The second part of this section had the participant open and use the Solar Calculator widget to investigate rooftop solar feasibility. The participant was guided through using the 'select building' procedure, where they navigated to a specific building and clicked on it. Each component of the results section was described and the user was encouraged to investigate how the results changed when they adjusted what percentage of the rooftop was allocated to PV panels. These steps were then repeated for a nearby building with different roof properties, providing an example of how the results might contrast significantly. Next, the 'draw area' procedure was used by the participant to investigate a specific part of the same building's rooftop. Emphasis was placed on comparing north and south facing roof areas to show how PV feasibility varied significantly based on roof topography. The building was a detached, single-family dwelling in the Black Creek neighbourhood. It was selected because the tree canopy cover in the front yard (facing north) impacts the total insolation received on part of the roof. This helped contrast the value between the two selection methods.

4.3 Workshop Questionnaire

A questionnaire was developed and included in the workshop exercise as the primary data gathering method. Closed- and open-ended questions were developed to solicit information from the participants to meet the research question objectives described earlier in this chapter. Closed-ended questions were used to gather responses that were comparable among participants. In most cases, the Likert scaling method was used for these as this provided an unambiguous scale of subjective user perceptions both in positive and negative directions. These kinds of questions also minimized the amount of work requested of each participant in contrast to requiring written responses for each question. Open-ended questions provided an opportunity for participants to share any relevant thoughts or opinions that may have not been considered when developing the closed-ended questions. In most cases, optional open-ended questions were provided at the end of each section in order for participants to supply additional information on the components dealt with in that section, if interested. These kinds of questions are generally the only suitable way to gain information on suggested features, changes, or details on bugs that were experienced.

All of the included questions were developed through an iterative process that sought to both get the user thinking about how useful each component of SunSpot was for them or others, while also revealing information on usability. Questions were designed to be unambiguous and only inquire about one specific concept or feature to avoid 'double-barrelled' questioning or misinterpretations that would result in biased and incomparable responses (Babbie, 2006). The length of the questionnaire and script together was designed to be completed in approximately 90 to 120 minutes. This was tested by fully reading and completing each step in the script and filling in each response, which took approximately 95 minutes.

Questions in Sections one to three followed a common pattern where the usefulness of the component or functionality investigated was queried using a five-point Likert scale ranging from "not helpful" to "very helpful". These questions were asked regarding the participant's personal use as well as their opinion on how it would affect those in the general public. These questions were supplemented with an opportunity for the participant to further elaborate on their response. In some cases the participant was asked to rate the ease of use of a component on a five-point scale and elaborate on their response. While both helpfulness and ease of use are subjective and are likely based on the comfort level and expertise of the participant, these responses, when aggregated, may identify components that are generally seen in a similar manner, requiring further investigation.

In one specific case, participants were asked to choose between which of the surface temperature visual representations were most useful. This was intended to reveal whether advanced visualisation techniques were advantageous or a hindrance to more easily communicating complex data. One visualisation style may be more intuitive than the other, while the other may present a stronger ability to investigate the data. Including a text response for why the participant selected the response they did would help develop an understanding, if there was a consensus, of what makes one method superior over the other.

After investigating the solar resource data and the Solar Calculator widget, participants were asked to describe the potential usefulness of solar resource data for specific periods of time instead of, or in addition to, the annual data that was included. This was done using a five-point scale where each participant is asked to rank the different ranges including annually, monthly, bi-monthly, or for specific days such as the summer solstice. This question was included as it inquires about the value of datasets that were modelled but selectively omitted from the application. While originally omitted to reduce UI clutter and possible user confusion, it may be possible that yearly visualisation of solar resource data is not ideal for certain user types with different interests or needs.

Section four of the workshop asked users on a five-point scale to judge the usefulness of different components of SunSpot at different spatial scales. These included the building level, the neighbourhood level, and city-wide. These responses can help identify at what scale users are interested in investigating different climate change issues. This relates to how these tools can be used by different types of decision makers whose initiatives are enacted at specific scales. Understanding the perceived value of these tools and data at different scales can also shape future application design as functionality can be optimised for certain tasks.

4.4 Participant Selection

The criteria for participants sought for this study were based on the target audience that was identified in Chapter 3. This includes two groups: professionals who are interested in climate change issues at different scales in the city and members of the public who have a general interest or curiosity in local climate change factors and opportunities such as rooftop solar power. It was also necessary for candidates to be located nearby as to facilitate an in-person workshop that would require approximately two hours of their time. Ideally, candidates would be from or around the Toronto area and would have a general understanding of the city's geography. This would mitigate possible confusion by testing an application in a study area one is unfamiliar with. Due to the length of the workshop exercise, an interest in local climate change issues, Web-GIS, or SDSS was preferred in order to minimize the potential for incomplete surveys.

In early 2012, a number of professionals from different public sector offices in Toronto were approached about participation in the study. These included individuals from planning and development positions at the City of Toronto and the Toronto Region Conservation Authority (TRCA). Many of these individuals have also been previously aware of the project through a number of telephone, email, and in-person meetings where parts of the GEOIDE project were discussed. In some cases, the individuals had provided input concerning the early stages of the solar modeling and/or thermal imaging visualisation. While local climate change issues, the FIT program, and rooftop PV generation are not specifically their expertise, most of these individuals were aware of the issues and are in a 'decision maker' role at the city or region level.

Twelve individuals expressed interest in testing SunSpot in 2012 through phone and email conversations. Of these, six were ultimately able to be scheduled at a mutually agreeable time in late August to participate in an afternoon workshop session to take place at the University of Toronto. This session was longer than the required amount of time for the script and associated survey questions as another component of the GEOIDE project was also included. This, along with the full-time work schedule of all potential candidates likely contributed to the challenge of arranging a date and time that maximized participation.

After the execution of this workshop it was identified that a greater number of responses would benefit the sample by possibly providing a greater consensus on some opinions expressed in the first set of responses. Students from two third-year GIS classes at the University of Waterloo were approached in November, 2012 through a short in-class presentation of the project and SunSpot in particular. This group was identified as a suitable set of candidates as their academic background suggested they were interested in GIS and possibly Web-GIS, SDSS, and climate change issues. They were also locally available and would possibly be able to participate with relatively short notice. These individuals would not be considered 'decision makers' in the traditional sense and likely do not hold personal stake in rooftop PV generation for dwellings in Toronto. Nevertheless, this allows for testing of the application from an interface perspective and if the data and tools being shared are useful.

The two classes had a moderate amount of overlap in the students present, making the total number of individuals solicited around 30-40. By a week after the in-class presentations, three students expressed interest in participating. These individuals were scheduled for two two-hour workshops that took place in the second last week of November at the University of Waterloo. Two sessions were used to accommodate the students' schedules.

4.5 Workshop Execution

The first workshop was conducted on August 28 at the University of Toronto. Lab space was provided by John Danahy, a professor at the University of Toronto in the Faculty of Architecture, Landscape, and Design who is also a member of GEOIDE Project PIV-32. The lab was scheduled to take two hours in addition to approximately one hour for introduction and a presentation by Dr. Danahy and his graduate students for another component of the GEOIDE project. A lunch was provided that took about 30 minutes of time in addition.

Participants were collectively shown Dr. Danahy's work through a presentation using a projector stationed at a common sitting area in the lab. Once complete, this setup was then used to introduce the Toronto climate change visualisation project and the SunSpot Web application. A brief guided tour of the functions of the application was conducted in order to make the application more approachable on first use. This action served to replace a potential web page that describes the project and provides information on relevant climate change issues so that the user is aware of the function of SunSpot. They were then introduced to the workshop script, given a brief description of the tasks that will be completed and questions answered, and each given a physical copy. Participants were also asked to read and sign a participation agreement from the University of Waterloo assuring that they are aware that the workshop has passed an ethics review and understand that they could cease participation in the workshop or decline to answer any question at any time.

Once the introduction was complete, participants selected one of a number of available computers where SunSpot had been opened in a web browser. These computers were a number of laptops loaned from the Faculty of Environment at the University of Waterloo. They were attached to desktop monitors that were available in the lab as well as computer mice packaged with the laptops. Once settled, each participant was visited and a brief discussion occurred to make sure the instructions and objective was clear. In this workshop, participants ultimately grouped together, which changed the dynamics of the workshop survey. This issue is discussed in greater detail in Chapter 5 as it closely ties in with the results of the workshop and survey.

The second set of workshops was conducted on November 12 and November 13, 2012 in the Spatial Decision Support Lab at the University of Waterloo. The first workshop consisted of two participants while the second consisted of just one. Each participant was provided with a copy of the official workshop invitation letter that introduced the project, provided details on how the workshop is conducted, and a consent form to sign that made sure they were aware of their rights. A brief introduction was provided with a short presentation of SunSpot and a verbal description of what the objective of the application is, and in informal terms, what the objective of the workshop was. This helped structure the mindset for the participants, so that they were able to understand what to be considering when testing the application.

Once this introductory process was complete, the participants were each seated at one of two available computers where SunSpot was open in a web browser. These computers were desktop PCs native to the lab and were located on the local area network (LAN) with the server that hosted the data and services that powers SunSpot. The participants spent most of the time working quietly, interrupting only for a few points of clarification on what certain survey questions were asking.

4.6 Chapter Summary

This chapter described the process behind designing and executing a series of workshops that aimed to obtain useful information on the success of the design of SunSpot. This was accomplished by identifying sources of potential participants that would be able to provide meaningful input. A workshop script was constructed that guided participants through testing each component of the application. Survey questions embedded in the script provided a means for gathering responses from each participant regarding each component of SunSpot.

The next chapter presents the results from this workshop, and discusses what was identified by the participants as effective or ineffective. Any trends in responses are identified and discussed. These are discussed in a manner that investigates the rationale for changes to be implemented in SunSpot and to provide lessons for improved design of future Web-SDSS applications for similar functions.

Chapter 5 – Results and Discussion

The previous chapter described the design of the workshop and questionnaire that were used to answer two of the research objectives of this thesis. The first was to test SunSpot's effectiveness in communicating local level climate change issues, and the second was to identify and provide recommendations for the future development of SunSpot and similar Web-SDSS tools. This chapter investigates the results of the workshop in the context of these questions. Section 5.1 describes the outcome of the workshop from a logistical perspective, detailing the participant turnout, their use of SunSpot in the workshop, and any general issues that were observed. Section 5.2 details the questionnaire responses and in-person observations and discussions with participants by synthesising them into three distinct themes: user interface and tool design, geovisualisation and map literacy, and interpretation of the modelled data. Section 5.3 discusses participants' feedback, their likely cause in terms of application and data design, their impact on the success of the application, and possible courses of action for future improvement of this and other applications. Section 5.4 summarises the findings in this chapter.

5.1 Overview of Workshops

The main workshop held on August 28, 2012 at the University of Toronto was attended by all six individuals who were scheduled to be present. In addition, three graduate students who were present to support in presenting the research conducted by Dr. Danahy's team also volunteered to participate in the workshop. As planned, two presentations were made to the participants at the start of the session: one by Dr. Danahy's team and one that introduced SunSpot and provided a 10-minute overview of its functionality. Four laptops connected to monitors, keyboards, and mice, as well as additional computers already present in the lab for the graduate students were available for use.

Five of the six non-student participants elected to form two groups among co-workers and complete the script together. In these cases, one participant tended to control the mouse and keyboard while the others offered input and participated in group discussions about how to complete tasks and interpret the results. Groups also discussed their perceptions of the tools and steps taken to complete tasks before completing questions on the questionnaire. One group elected to complete one questionnaire by collaborating on responses and having one participant fill in the group response. The other group worked to complete two questionnaires, but one member elected to take their incomplete questionnaire with them at the end of the session.

The three graduate students worked to complete one questionnaire together, collaborating on each response. Towards the end of the session, two of the participants excused themselves to begin disassembly of their equipment, leaving the third to complete the final section and submit the questionnaire. Excluding a 45 minute lunch break and a 15 minute introduction, the workshop script and questionnaire took approximately two hours to complete.

The second set of workshops was completed at the University of Waterloo on November 22 and 23, 2012. All three students who expressed interest through email were in attendance. Each participant arrived at a different time and was personally introduced to the research project and given a brief introduction to *SunSpot* through a short guided tour of functions and the overall design rationale behind the application. Participants signed participation consent forms and spent approximately 90 minutes completing the script and questionnaire. During this time, participants asked some questions regarding clarification of the steps listed on the script or wording of questions on the questionnaire, but interaction between the participants and facilitator was minimal in contrast to the first workshop.

5.2 Workshop Results

This section presents the results divided into thematic sections that allow for synthesis of the questionnaire feedback as well as in-person observations and discussions. Section 5.2.1 presents feedback regarding the design and implementation of the user interface and the tools that are present. Section 5.2.2 includes feedback relating to how well participants understood the data layers and visual results that were produced by some tools, while Section 5.2.3 focuses on the modelled solar resource data and how participants responded to interacting with these data and the estimates calculated by the Solar Calculator. While most of the feedback was synthesized into these sections, some responses were not included in this chapter as they were unrelated to testing SunSpot and answering the two research questions being investigated.

In this chapter a number of results from Likert-scaled questions are presented in the form of bar graphs. In most of the cases the graphs reflect the number of respondents who answered each option. The graphs in Figures 5.6 and 5.7 reflect the sums of the converted values, where each rank of preference is scored between one and five points. Due to each question being answered by only six to eight participants, no statistically significant findings can be derived from these results. However, they can serve as a general indicator of any consensus of opinion among participants. These questions are more likely to be useful in future research when a greater number of participants are reached through online study as described later in this chapter.

In addition to the Likert scale graphs, a number of quotations are included that were obtained from the written questionnaires submitted by participants. These quotes are included in-line and are preceded with a unique identifier to make referencing easier. Many of these responses were written in informal language and in some cases have been edited for clarification.

5.2.1 User Interface and Tool Design

Both in-person observations and questionnaire responses showed that participants had no problems with SunSpot's basic navigation tools. The feedback provided about map navigation tools were almost all regarding the Address Locator. Participants found that the address locator was not robust enough to match synonyms, especially with address suffixes such as "st" instead of "street". Other responses mentioned the lack of a method to close the search results tab if the user elects not to select a result. One commented on the lack of a pin or marker appearing on the map to denote the location of the selected address.

The responses corresponding with the use of the Landcover Chart also identified some interface navigation challenges experienced by the participants. In two cases, one written and one through a verbal discussion, participants were unclear about how one might change between investigating building parcels and neighbourhoods with the Landcover Chart. Discussion concluded with the explanation that the map zoom level governs which layer is active and is denoted by the label on the selection button in the widget. The group of participants suggested that a change be made to clarify this behaviour as the text description on the tool was unclear.

A number of participants commented that in some cases widget windows as well as the introduction window would be more useful if they could be selected and moved by the user by dragging them with the mouse. In both cases, the objective was to move them in and out of the way of the map frame view without closing or hiding them entirely. A discussion about this with one of the participants in the second set of workshops revealed a perception about freedom of control of the interface. The participant felt that the widget window looked movable and therefore should be movable if the user desires to.

5.2.2 Geovisualisation and Map Literacy

Data Layer Visualisation

The way in which data layers were presented was an issue brought up in a number of cases by many participants. The Landcover Chart was generally considered useful by the participants (Figure 5.1), but some also suggested that additional usefulness could be gained by having the land cover data available as a map layer. This would be in addition to the available layer that displays the vegetation class. The colour gradients used for the solar layers and the surface temperature layers was confusing to some users (Q1, Q2). Questionnaire responses as well as in-person discussion pointed to the confusion of the two data sets using the same colour gradient, making it unclear in some cases how they were different.

Q1: Appealing presentation – some confusion between temperature and solar.

Q2: [The] colour ramp resembles heat readings.

The discussion concluded that a component of this issue was how the solar data closely correlates with sunlight hours and shaded areas, making it visually comparable to "hot and cold" areas. One participant suggested that without temperature readings, some of the "hot spots" may imply to a user that it is an unsafe or vulnerable area (Q3). Perceptions and bias can lead users to develop a false understanding of results. Preventing a user from thinking that a red or "hot" area is inherently negative is important when developing maps (Campbell, 2001). One option to resolve this would be to include "tooltips" that displayed surface temperature or solar radiation at an area when the mouse hovered over it.

Q3: Good for a general understanding of heat vs. land use, but people may think they are vulnerable in a hot spot.

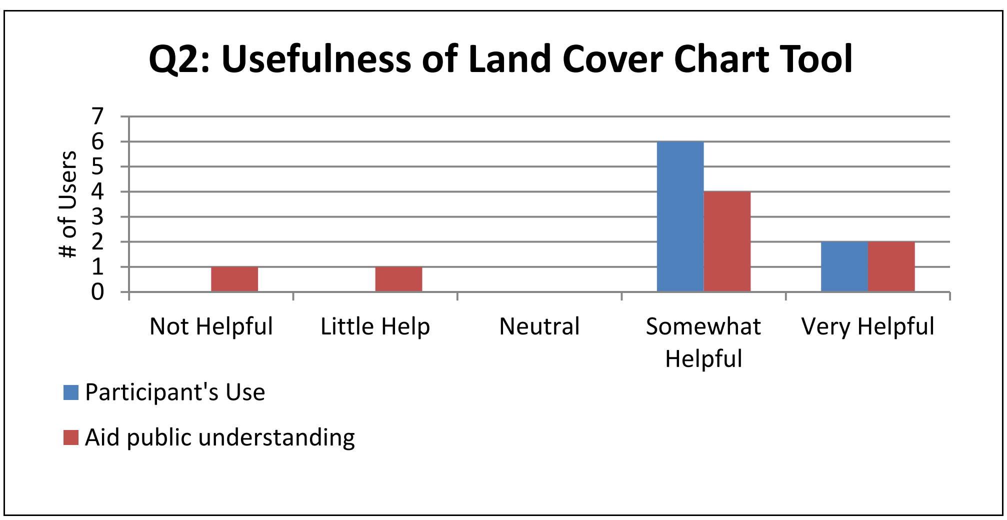


Figure 5.1: Rankings of usefulness of Landcover Chart

Surface Temperature Data Visualisation

Participants generally considered the surface temperature datasets to be useful both for their own use and for public use in understanding the link between environmental issues and surface temperature (Figure 5.2). Participants found the data useful for understanding heat issues and being able to quickly compare temperature with land cover and aerial imagery. One participant commented that the tool was particularly useful for zooming in on unusually "hot" or "cold" areas on the map and investigating what the cause may be.

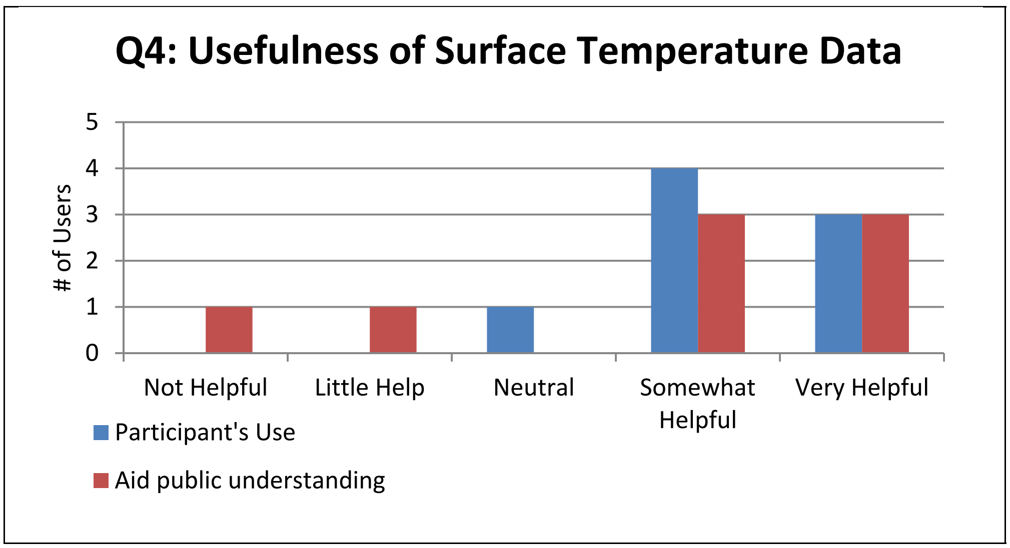


Figure 5.2: Rankings of usefulness of surface temperature data

A significant question posed to the participants was about the usefulness of the two available surface temperature visualisation techniques. When participants were asked to choose which was more useful, the responses were split. Some participants argued that the degrees above or below the daily mean option was useful once it had been properly described in-person as the legend was insufficient (Q4, Q5). One participant wrote that it "...provided a foundation for a stronger rhetorical argument..." as it allowed different dates to be compared in a more objective manner. Other participants preferred the surface temperature values method as it was an easier concept to understand. One response articulated that the public is not interested in standard deviations of temperature (Q6). Another response pointed out that the difference from daily mean was not intuitive and required an explanation. Speaking about both methods, one participant suggested the option to display either the raw, non-interpolated surface temperature rasters or the existing interpolated rasters that had smoother transitions between cells. In one instance a participant was unclear on how the thermal data was derived, wondering if each available time was a time-dimensionless snapshot or an average of multiple points in time.

> *Q4: [Degrees from the mean] needs to be described and explained before it can be understood.*
>
> *Q5: [Degrees from the mean] is helpful once the legend [and standard deviation] is explained.*
>
> *Q6: [The] public does not care about standard deviation.*

This feedback touches on the challenge that exists with dynamic mapping as the author no longer has as careful control over the look and contents of the map (Morrison, 1997). New capabilities such as transparency levels, altering colour gradients or even, in this case, altering the visualisation format of a layer can be useful, if the challenge of over-complexity can be overcome (Kraak, 2004).

Land Cover-Surface Temperature Relationship

A large component of the script and questionnaire was centred on investigating how participants used the Landcover Chart tool and surface temperature data together. Participants identified that using these tools in combination was generally useful at investigating the relationship between surface temperature and land cover in the study area (Figure 5.3). One response commented on the usefulness of being able to quickly "cross-reference" land cover with surface temperature by using the Landcover Chart in conjunction with the surface temperature layers. One participant commented that the differences in resolution between the land cover data and surface temperature layers was insufficient for investigating these linkages at a larger scale (Q7). Other participants commented on the lack of discrete temperature values or a way to query these values in the mapped layers outside of the Thermal Transect tool. Another participant suggested that it may be ideal to display individual temperature values in some manner on the map along with the rasters. This was considered as a potential option but was not implemented due to the large number of values that would have to be displayed.

Q7: The differences in resolution can not give us the detail we are looking for.

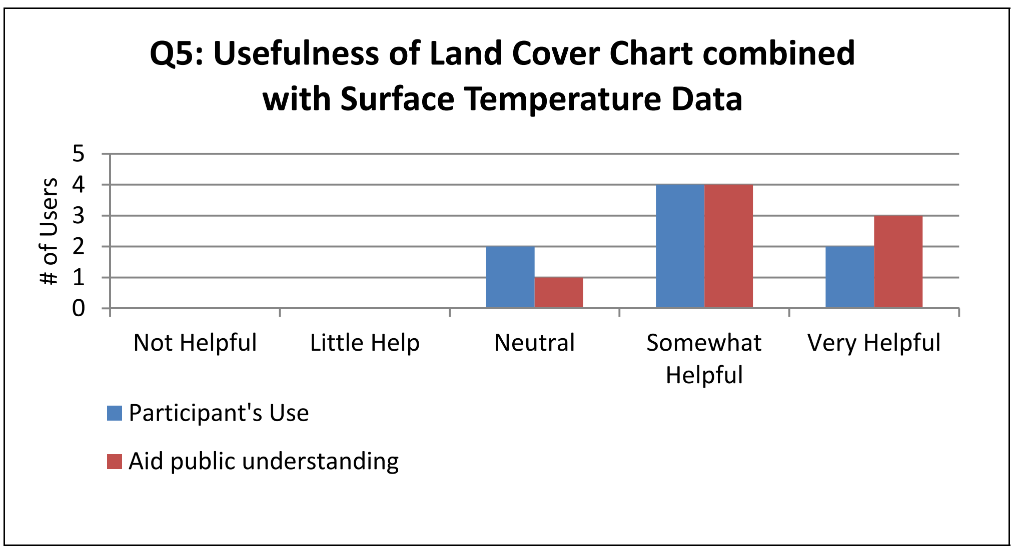


Figure 5.3: Rankings of usefulness of Landcover Chart and temperature data

The Thermal Transect tool was also generally seen as being useful for personal use as well as aiding the public's understanding of surface temperature's link with environmental issues (Figure 5.4). Participants found it useful to investigate how the temperature changed along walking or driving routes. The tool was also informally used in some cases to understand how much the temperature changed between different features seen on the aerial imagery as well as different land cover types. A common suggestion was to include additional data that would increase the usefulness of the surface temperature data and the Thermal Transect tool; some suggestions included air quality data layers and traffic data (Q8).

> *Q8: I think it would be great for planners and public health workers (an air quality or traffic flow layer would be great!"*

One group of participants suggested that it would be very useful to include network analysis functionality in order to create pedestrian routes that consider surface temperature as a factor when routing. This was also considered during the development process but was not done as it was outside of the scope of the tool due to the amount of time available.

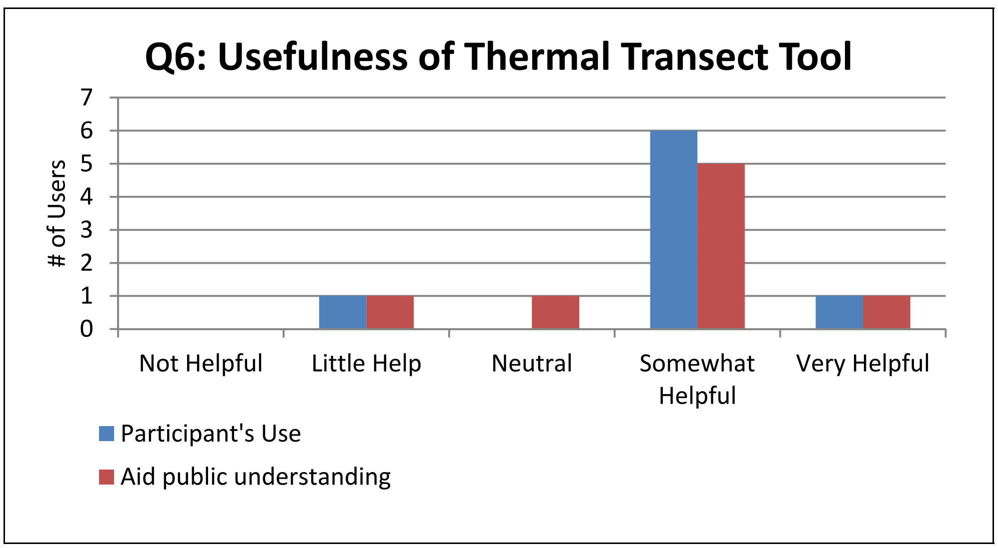


Figure 5.4 – Rankings of usefulness of Thermal Transect

5.2.3 User Perceptions of Modelled Data

A significant part of the workshop was to expose participants to the solar resource modeling data and tools to better understand how effective they are in communicating environmental issues relating to planning and developing strategies and for communication and public outreach. Participants generally perceived the data layers to be useful for these applications (Figure 5.5.) One participant voiced this by commenting that the data layers made it easy to communicate to the public what potential there was for engaging in solar power use and that it enables planners to optimize solar capacity (Q9).

> *Q9: I think there is great potential with this dataset – both in planning for determining optimal orientation and for homeowners to investigate solar potential.*

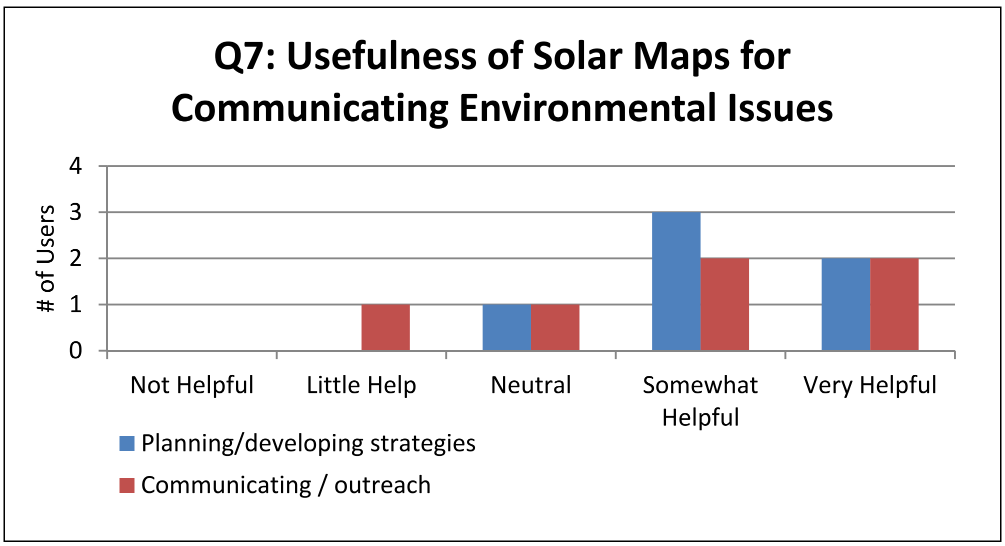


Figure 5.5: Rankings of usefulness of solar maps

There was concern among some members regarding the display of vegetation and its meaning of how tree canopy cover affects solar resource potential. One participant was concerned with how the results may suggest that removing trees would improve solar resource, while having a net negative impact to the local environment through factors such as albedo and air and surface temperature. Another participant was curious about the significance that coniferous versus deciduous trees have on roof shading. Responses like this made it evident that the participants were interested enough in the data and tools that they were curious about the potential for using these data for uses other than what was intended in the workshop script.

A number of participants were unclear on how the different values for the Solar Calculator were estimated. They inquired during the workshop about how the dollar savings, carbon savings, and solar potential in kilowatt-hours per square metre were calculated. This indicates that the documentation requires improvement. Two suggested features regarding the solar resource data were described by two participants in the questionnaire. One mentioned that the data had the potential to help determine the optimal orientation for future rooftop configurations. The other suggestion was to include a subsystem of the Solar Calculator that permitted users to compare potential savings estimates with estimated costs of installing at PV system of a comparable size.

Participants were asked about their perceptions of how useful solar resource data would be if generated as displayed in the workshop for different periods of time. Four periods inquired about were, monthly, bi-monthly, or during specific days of the year such as the summer solstice. Figure 5.6 displays the overall perception of each option based on the ranks for Likert scaling being translated to values between one and five and added together. These rankings were formed by converting each option to a numerical score. “not helpful” was ranked 1 and “very helpful” was ranked 5. This would enable the ranks to be added together to give a general score of overall perception. While only five questionnaires contained responses to these questions, these respondents were generally more in favour of the annual and monthly options as opposed to the bi-monthly or specific days (Q10, Q11). In the written responses that accompanied this question, participants identified that the annual information helps best describe the overall picture of cost/benefit while monthly would display seasonal changes. One participant opined that solar data for the growing season would help expand the usability of the application for urban garden and other agricultural purposes.

Q10: Annual figures give the best overall picture of cost/benefit.

Q11: Annual information explains change over time best and monthly information explains explains seasonal fluctuation best.

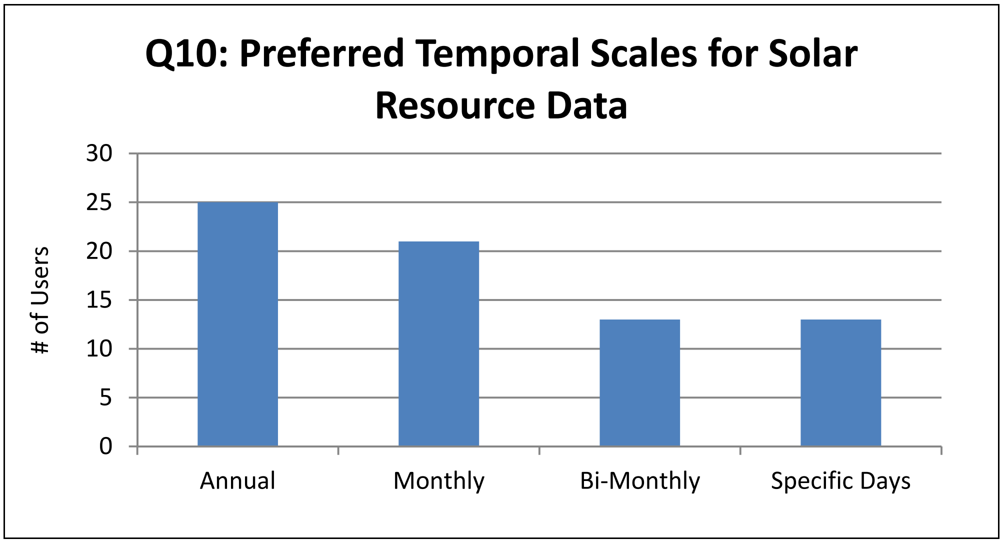


Figure 5.6: Sum of rankings of preferred temporal scales

The final section of the survey and questionnaire investigated participants' opinions on the usefulness of a number of data and tools at different scale levels. This included the unclipped and clipped solar resource layers, the surface temperature layers, and each of the Landcover Chart, Thermal Transect, and Solar Calculator tools at three scales: building, neighbourhood, or city-wide. Figure 5.7 displays the general opinion of the six respondents by adding together each group's responses based on a value for each scale option between one and five. This results in a possible minimum of six, where all respondents found the option to be "not useful" and 30, where all respondents found the option to be "very useful". This question was not accompanied by an open-ended question for comments and opinions.

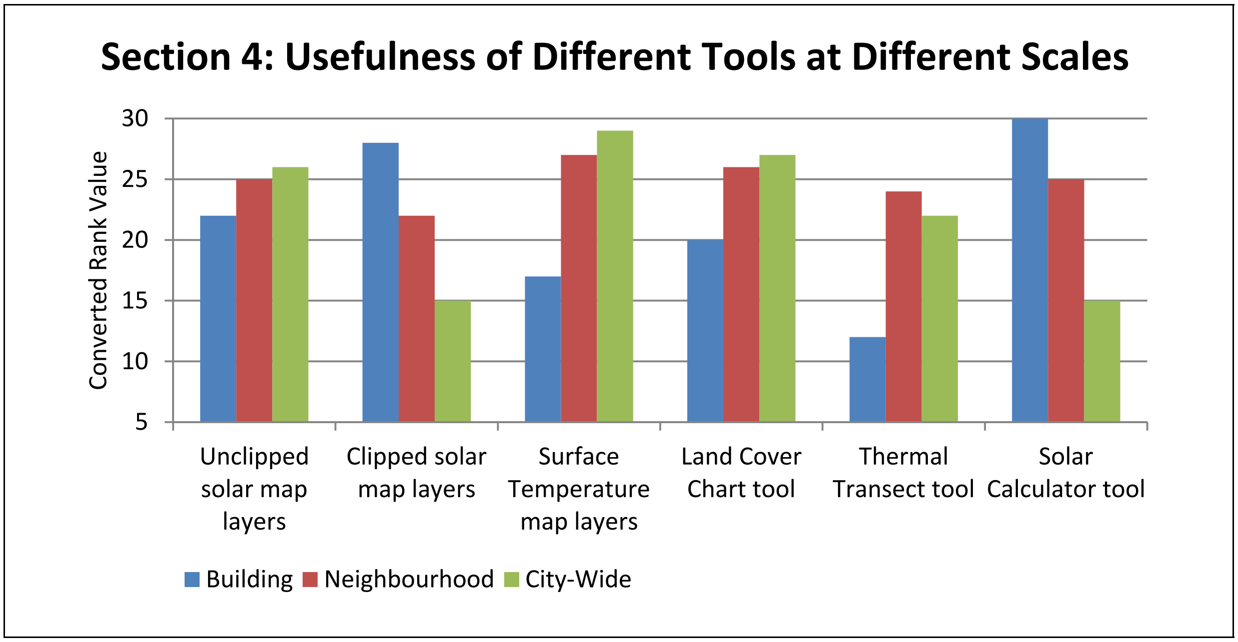


Figure 5.7: Sum of rankings of perceived usefulness of each tool at different scales

5.3 Discussion

This section discusses the results in the context of the two research questions being answered by the data obtained through the workshop. Divided by each common theme, a number of issues relating to specific data, tools, and workflows are analysed, seeking to understand the cause and potential resolution to each issue. Suggestions for future research and design opportunities are provided where relevant.

5.3.1 User Interface and Tool Design

Address Locator

The comments received about the functionality and design of the Address Locator describes a number of problems with the tool that should be resolved before future testing or public deployment of SunSpot. The geocode service is likely being too restrictive in its matching of street types, where “st” and “street” are not considered synonymous. This is a problem that can be resolved by further testing of addresses and adjusting the matching system to weigh the street type less than the other components of the address or switching to an address locator service made available elsewhere. Adding a place name alias table will allow participants to search for named places in addition to addresses. A close or cancel button should be added to the drop-down menu that enables users to cancel out of the workflow of zooming and panning to a queried address if they decide that none of the results are suitable. It is also ideal to add a temporary pin when a user selects and zooms to an address result.

Solar Calculator: Draw Area Tool

One comment about the Draw Area tool in the Solar Calculator widget was that it was not as useful compared to the Select Building tool because the roof percentage slider is disabled, not allowing users to select a fraction of the drawn polygon. When these tools were developed, the conceptual workflow for the Draw Area tool was that participants were interested in drawing where they would want solar panels to be placed. In exercise, participants were interested in using this tool to sketch an area such as a roof segment and select a fraction of that for potential solar panel placement.

Movable Widget Windows

A number of suggestions involved the requested ability to move frames around manually as opposed to them being fixed, or in the case of the widgets, on a slider at the bottom of the screen. These were designed like this to reduce clutter and minimize potential user confusion. Both options would have to be tested in future sessions as it is possible that some users would find the movable windows less effective.

A common theme in the feedback for these UI components and tools is that the intended use when designing each does not always reflects the actual use in practice. While each of these tools was designed to best suit a certain workflow or behaviour, some participants were interested in using them in different ways. While many of these suggestions can be implemented with little impact to the overall function of the tools, this shows how important it is to solicit open-ended feedback from users regarding UI and tool design.

5.3.2 Geovisualisation and Map Literacy

Misinterpretation of Data

Some participants commented that some of the data may be misinterpreted in a number of ways. The way in which data was visually presented contributed to this, where some participants were confused on the difference between surface temperature and solar resource layers as they use the similar gradients. In addition, both raster layers exhibit similarities in patterns, as areas in shade receive less radiation and are therefore coloured as a "cooler" area. Confusion over "hot spots" in the surface temperature data had one group of participants wondering if future users might think these areas are where they're vulnerable due to the perception that the area is excessively hot.

Non-visual results could also be misinterpreted if communicated improperly. One participant suggested that some of the Solar Calculator results may imply that trees could be removed to improve rooftop solar potential in the subject area. While tree shading can significantly reduce rooftop solar potential, it is not advantageous to reduce canopy cover and sacrifice a myriad of other benefits provided by the vegetation. The rationale behind displaying tree canopy shading is simply to communicate that it is a factor to be considered when placing solar panels on a roof. It is possible that this needs to be better communicated in a way to avoid delivering an unintentional narrative that tree canopy cover is undesired. Future testing that involves a greater numbers of participants may shed light on the need for this change.

Some data may be misunderstood due to its complex nature. One of the challenges met when developing SunSpot was to balance functionality with ease-of-use in order to make the application useful for a wider audience and less dependent upon having GIS and remote sensing training. A prime example of this is the Weatherspark Web-map, which works toward visualising complex weather data in interactive ways that are more easily accessible to a broader audience (Diebel and Norda, 2013). The solution to visualising surface temperature in a manner that allows it to be compared over time, as described in Section

3.4.4.3 was tested. Participants shared both positive and negative opinions toward the usefulness of both visualisation options. Generally, these perceptions were with regard to usefulness versus understanding as responses commented on how the "normal" option was not as useful in analysis, but the standard deviation method was likely confusing or unimportant to the general public. It is likely that both options play a role depending on the audience, but communicating the advantages and drawbacks of each is paramount in assuring they are used properly. This is a common problem when designing maps, as different audiences have different expertise and needs. Often the solution is to govern access to different map data based on the perceived needs of different audiences (Krygier andWood, 2011).

Added Data and Geovisualisation Functionality

Many participants suggested the inclusion of additional sources of data as well as the enhancement or addition of tools for conducting further investigation of local scale environmental issues. Adding functionality to examine air quality, growing seasons, or to develop thermal transects as network paths, for example, both add to what the application can be used for as well as its complexity. It is important to focus on the intended uses and users of the SDSS and avoid stretching functionality beyond the needs of the core user base. Nevertheless, identification of potential functionality and data themes that are interesting to participants can generate new research possibilities worthy of investigation. One example provided by a user was that the existing transect tool might be useful when combined with additional data such as traffic, to create a route planning tool that accounts for a healthy and comfortable route (Q12).

> *Q12: [We] think the transect tool has amazing potential with other data such as traffic for route planning - healthy – shade/volume*

As discussed in Chapter Two, a large source of power for Web-GIS is in the use of APIs, common standards, and utilization of map services from other parties as "mash-ups". Instead of developing a Web-application that attempts to meet every need, many of these possibilities can be realised through the development of new applications. By publically serving data such as the solar resource or surface temperature layers, other authors can further innovate and develop customized solutions for these uses (Schmidt and Weiser, 2012).

Tool and Data Usefulness at Different Scales

Only six participants had completed the final section of the questionnaire that asked about the usefulness of various data and tools at three different scales. While this low sample size is not sufficient to identify any trends in the perceived usefulness of components at different scales, it can be generalised in some cases that certain tools are considered useful or not useful. In cases such as the thermal transect being unanimously declared "of least use" at the building level, or the clipped solar rasters or Solar Calculator being generally considered not useful at the city level, the reasoning behind these results is self-evident. The tools and data in question are not designed for those scales and cannot produce any meaningful results. For example, one of the lowest ranks is to the use of the Solar Calculator at the city-wide scale. This makes sense as this tool was designed specifically for buildings or small areas. However, if a similar tool was customized for use across the entire city, perhaps to identify overall solar potential as a city-wide goal, it may be considered to be more useful. Future research would benefit from investigating a more general question of "what scales are different data themes interesting to you?" This will help shed light on how these tools might be designed to meet demand.

5.3.3 Modelled Solar Resource Data

User Assumptions and Uncertainty

As discussed in Chapter Three when the methodology behind generating the solar resource data was described, there are a number of assumptions being made that affect overall accuracy and precision. This is also true for how solar potential, potential savings, and estimated carbon savings are calculated. Better understanding the significance of these assumptions, especially in a quantifiable manner would be a considerable undertaking and is not an objective of this research. However, the feedback obtained from the workshops reveals that it is still important to communicate to the user what kinds of assumptions are being made and how they might conceivably impact the results.

Similar applications handle these uncertainties in different manners. The City of Boston Solar Map has a tab displayed alongside the calculated results, which describe the various assumptions made when calculating the results. These assumptions include generalisations about certain properties that may vary, such as assuming all rooftops are flat, using a single averaged value where the real value may vary, or including user restrictions such as not permitting 100% of a rooftop to be allocated to solar panels. The PVWatts tool does not list assumptions but does link to an external web page that describes how the calculations were produced. As a third example, the San Francisco Solar Map combined both of these options with a description of how the estimates were derived, including the assumptions being made in the calculations. None of these tools make an attempt at describing how significant the assumptions are.

SunSpot adopted a few of these options such as limiting the user's selection of roof to 75% and providing a tab to describe how the calculations were derived. Unfortunately this tab was left unpopulated for the workshops, but should be completed before any future workshops are conducted or the application is published. However, due to the complex nature of how the data and calculations were derived and the number of assumptions made, it is likely more ideal to use an external page or a pop-up with more screen area to include annotated images and more text.

Another possible assumption users can make about the results is their reported precision. While this was not identified as a problem or mentioned in the feedback, it is possible that the numerical precision may imply a certain level of accuracy. The Solar Calculator provides estimates to the nearest dollar, hundredth of a ton of carbon dioxide, and kilowatt per square kilometre. All other similar applications that have been investigated report values to these levels of accuracy and do not provide margins of error. While it is possible to have the tool round the calculation to a broader estimate, this may imply that there is a known level of uncertainty and therefore the broader numbers can be considered accurate. Like the other proposed resolutions for communicating uncertainty, a reasonable solution may be to communicate that these values are not exact.

Evaluating Feasibility

One challenge that comes with the inclusion of dollar savings estimates is that these are not necessarily meaningful values that help users gauge feasibility. One participant suggested that estimated installation costs should be included in the calculated results in order to give users a reference when evaluating feasibility. A possible alternative is to link to a government or other well-trusted web site that discusses and provides estimates for possible photovoltaic vendors. The challenge is to provide this data in a manner that is unbiased and does not strongly suggest to the user that the hardware would be an exact cost and that they could recoup a specific amount of money over its lifespan.

An alternative solution to communicating feasibility to a user might be to use a rating system. This method could provide a ranking using a loose grading system such as a letter grade or star-level, which can suggest a level of feasibility when compared to a base line. This base line could be dependent on one-time calculations that estimate a financial or carbon break-even line, where values exceeding or falling below it could be issued an appropriate score or rating relative to similar areas or buildings in that city. Another option would be to compare the user's results with a pre-calculated neighbourhood average, providing a rank of how feasible their query is in contrast to the average feasibility of a neighbourhood. This alternative would not provide an estimate of feasibility but would instead rate the roof-in-question in comparison to others nearby. Users could then understand how their rooftop ranks in comparison to existing projects that share similar characteristics. An example of this method is a scoring system used by the HEAT web-application to rank homes in Calgary, Alberta by the amount of heat loss seen in Figure 5.8 (Hay et al., 2011). This method succeeds in communicating a severity of heat loss in a way that is understandable by the user without having to formally quantify the exact amount.

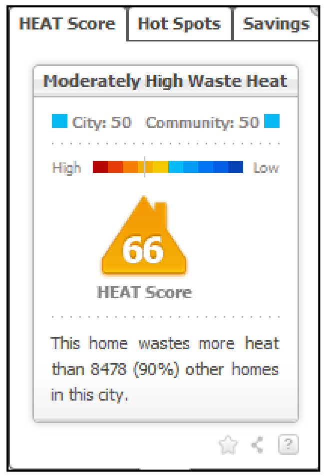


Figure 5.8: Score interface from the City of Calgary's HEAT application.

5.3.4 Efficacy of Workshop Design and Impact on Future Workshops

In addition to answering the research questions, the conduction of these workshops and the feedback gathered helps identify ways in which future testing can be improved. This is done by examining how useful the responses gathered were in answering the questions, identifying any areas of interest that were not satisfactorily investigated, and determining what changes to the script would improve these.

Likert Scale Questions

Most of the questions that asked participants to respond using a five-point Likert scale did not end up being useful in the analysis of the results beyond identifying if there was a unanimous opinion. The small sample size makes it impossible to derive any statistically significant results from the data, as the opinions of a few users can drastically alter the results. However, if testing was completed using a much larger audience, these questions would be useful in pinpointing areas of significance. This is especially useful when the sheer number of responses would make it difficult to identify common themes in feedback from the open-ended questions.

The last section of the questionnaire consisted of a series of Likert scale questions about usefulness of various tools at different spatial scales. It did not include an open-ended question where participants could discuss their responses. As discussed earlier in this chapter, some of the responses closely matched the expected outcome as certain tools were designed to be used at certain scales. Adding an opportunity for participants to explain their responses may shed light on alternative reasons for these responses.

Participants Forming Groups

As described in the first section in this chapter, some of the participants of the first workshop formed into groups. One possible contributing factor to this was the shortage of computers that would have required at least two participants to work together. Another possible factor is that it was never explicitly stated in the workshop script that participants must work individually. Groups were formed among those with existing work relationships, which for one group affected how they completed the exercise. It was observed that one member took a leadership role, while the other two executed the tasks and provided supplementary input into all discussion and decision making. For the group that submitted multiple questionnaires, it is possible that completing the workshop together introduced bias as the group actively discussed most aspects of the workshop. The formation of groups was avoided in subsequent workshops by ensuring enough computers were available and individually setting up each participant at a computer. In future workshops that take advantage of online testing, it is possible that multiple individuals will work together to complete a questionnaire. The impact this would have on results is uncertain

Additional Research Questions

As discussed earlier in this chapter, it became evident that too little explanation was provided for how the solar resource data and estimated values were calculated. In addition to the recommendations of adding suitable information about the processes, investigating if the participants understand these data and its assumptions and uncertainties is important. Additional questions would focus on determining if the supplementary information was useful and if the participants understood what the data was displaying and the significance of the assumptions being made.

Inquiring about the perceived usefulness of potential tools such as a ranking system for rooftop solar feasibility, added data layers, or other suggested features would help identify if there is a general interest in them. However, the challenge is avoiding scope creep by assuring that added features do not detract from the usability of the application. It is important to keep focus on a small number of key functions and expand functionality to support these, rather than building an application that slowly resembles a broad, open-ended SDSS.

Benefit of Future Research

The next logical step in the refinement process of *SunSpot* is to make the changes proposed in this chapter and then to expand the workshops online, targeting a broader audience including more industry professionals. The absence of any critical errors in the completed workshops suggests that SunSpot is ready to be tested by a much larger audience without the need of in-person assistance. It was important to ensure this was true using in-person workshops as any critical errors, oversights in workshop design, or misunderstandings in data presentation and results could generate a considerable amount of non-useful feedback. It is possible that significant errors can limit completion or distract participants from testing all components of the application. Inclusion of industry professionals would expose the application to additional experts with a more intimate understanding of solar resource estimation. These individuals would be able to evaluate and comment on a number of issues that cannot be tested by the general public. Some of these include getting an idea if the results are within reasonable ranges and are consistent with their expert knowledge.

Chapter 6 – Conclusion

The overall goal of this thesis was to investigate how local scale environmental initiatives might be communicated and made more accessible to individuals through the use of new Web-GIS technologies and decision support practices. SunSpot was built and tested as a way to determine the effectiveness of design improvements made, based on opportunities identified through the literature and existing Web-GIS applications. The first section of this chapter summarises how each research objective was met in order to achieve this goal. Next, a number of limitations to this project are described and possible resolutions are proposed. The chapter is concluded with recommendations for a number of future research opportunities identified from the workshop results discussed in Chapter Five and through the research and development stages of SunSpot.

6.1 Summary of Research Objectives

The first research objective was to develop a conceptual framework that identified the relationships between a number of relevant fields of study. Some of these include climate change initiatives such as the Ontario Green Energy Act, local-scale renewable energy opportunities, Web-SDSS, public participation, and new Web technologies. While environmental initiatives were found to be undertaken at all levels of government, it was clear that at the municipal level there are unique opportunities to involve the public more actively. This is because of the ability for local government to focus on programs that are most suitable to issues that are unique to their region. Engaging the public can be accomplished through an increasing use of Web-Based VGI and SDSS tools, where issues that traditionally require expert knowledge can be communicated with greater ease. This research shows how Web-SDSS and other Web technologies are an ideal way to engage the public by enabling them to participate as decision makers and therefore improve the chances of success of local-level environmental initiatives.

The second objective was to design and build a Web-SDSS that could be used to investigate how the opportunities identified by the literature review can improve engagement of individuals and other decision makers in environmental initiatives. This involved developing a number of spatial datasets that were published as web mapping services to be used by a number of tools and widgets that make up SunSpot. Solar resource rasters for each month in a typical year were developed using surface model data based on a number of sources including LiDAR and extruded flat rooftops as well as atmospheric transmissivity data. In Black Creek, the resulting solar rasters were highly detailed, which allowed for further investigation of the significance of rooftop geometry and features such as roof access and building climate control equipment. These data supported a number of visual layers as well as the Solar Calculator widget, which allowed users to investigate rooftop solar potential. Land cover and surface temperature data were also obtained and processed into a number of datasets that would support additional widgets used to investigate other issues. SunSpot was built off of the ESRI Flex Viewer, a Flex-based Web-application framework that provides a solid foundation for basic Web-mapping capabilities. This application provides an ideal environment for testing the design choices made as it was specifically developed for the audience and purpose in question. This also allowed the workshop script and questionnaire to be specifically catered to obtaining useful information on how well SunSpot met the desired functional capabilities.

The third objective was to test SunSpot's effectiveness in helping users to explore rooftop solar potential and, to a lesser extent, some components of urban heat effects. This involved testing the usability of the application, which relates to basic functionality and capability, testing user understanding of the results developed through the application, and testing user understanding and the value of different visualisation methods of the solar modelled and surface temperature data. Two sets of workshops were held at separate times and locations. They consisted of a total of twelve participants, six of which were professionals from the public sector in positions relating to environmental issues, and six were undergraduate and graduate students from the University of Waterloo and the University of Toronto. From these workshops, feedback was obtained through the submitted questionnaires, in-person observations, and discussion with the participants. Analysis and synthesis of these results provided a considerable amount of constructive feedback, which shed light on which design choices worked and which required improvement. New ideas and suggestions for additional features and future research were also solicited from the participants. Overall feedback regarding SunSpot was very positive, with a number of participants encouraging the publication of the application. Others stated that the usefulness of SunSpot for individuals curious about rooftop solar feasibility is evident.

The final research objective was to provide recommendations for the development of future Web-SDSS applications. This was completed as part of the previous objective as a number of opportunities for improving SunSpot and similar applications were identified through the workshop results. While participants successfully completed the script and generally understood the process, recommendations for an improved address locator, movable widget frames, and improved communication of tool function underline the importance of effective design. Many of the design choices for SunSpot came from adopting and improving on implementations of similar Web-applications. The literature on how to effectively design components of a Web-application is lacking, largely due to how fast capabilities and the use of Web technologies are evolving, but also due to the open-ended nature of Web-GIS; there is no one-design-fits-all solution (Tobon, 2005; Haklay and Zafiri, 2008). Providing meaningful results was an important part of SunSpot's objective. Feedback showed that while a number of improvements made were useful, others may possibly increase application complexity and over-complicate the results. This was particularly true for the visualisation methods for solar resource and surface temperature data. No other applications investigated opted to show solar resource layers, leaving them as behind-the-scenes components to be used by the tools. Including them allowed the participant to investigate the solar modeling data in greater detail and generate a stronger understanding, but it was evident that this can be unintuitive and counter-productive to some.

Further recommendations were made for how to improve the testing process of these applications. While there is literature on usability testing of Web-GIS applications, little was discussed on an ideal testing regimen for Web-SDSS, because the problems being investigated are ill-defined and often require significantly different design approaches. It was found that in-person workshops are an ideal first step, followed up by online testing. This provides an opportunity to test workshop script and questionnaire's effectiveness, identify any significant bugs, and closely control the environment in which the application is tested. Later online workshops would then benefit from improvements made to the workshop design. It was also noted that qualitative feedback methods such as open-ended survey questions and in-person observations and discussion provided useful information not obtainable by large-scale surveys using quantitative methods. This is, in part, due to the flexibility these methods provide, allowing user perceptions to be used as the gauge of effectiveness for ill-defined processes.

6.2 Limitations

There were a number of factors that limited the scope and capabilities of the research conducted in this thesis. The workshop questionnaire was designed with a combination of quantitative and qualitative questions. This was meant to develop an understanding of the overall user perception of the usefulness of various components, and then provide an opportunity for the participant to discuss specifics and share thoughts and other details. While the small sample size precluded statistical analysis of the Likert scale questions, they did provide some indications of participants' responses to tasks and questions in the workshop script. These data were supported by written responses to open ended questions, participant observations, and discussions with. It is likely that the Likert scale questions will be more useful in identifying tool effectiveness in online testing where there might be far more participants involved. Relying on written feedback from dozens, if not hundreds of users would be excessively time consuming.

There was a lack of detailed building and roof structure data from which to derive surface models for the solar resource data. As described in Chapter Three, the piecemeal manner by which topographic data was assembled happened based on the ability to obtain usable data. LiDAR topographic data existed for part of Black Creek and was treated as its own surface model, while the central core of Toronto used a combination of sources to extrude building footprints and combine them with a contour-based surface. In some downtown areas there were no building heights available. A decision was made to manually interpolate these heights using aerial imagery, building type, building shape, and neighboring buildings. An incomplete patchwork of suitable test areas would complicate testing and draw focus away from the application design and the overall understanding of the results.

As SunSpot improved on similar applications by providing considerably more visual layers for a user to investigate, this had the effect of greatly increasing the amount of data that had to be transferred. One common way to minimize load times is to cache map data as tiles at specific map scales, making them available for transfer immediately. However, this was not feasible in ArcGIS Server 10.0 as raster mosaics could not be combined with the feature of publishing multi-layer tiled caches. Informal online research indicated that this might be a bug and may be resolved in a future build of the software. Resolving this could be done by waiting for a bug fix, avoiding the use of a raster mosaic, or publishing each layer as an individual map service. However, the latter two options are less than ideal as the alternative to a raster mosaic are rasters with very large dimensions in order to capture both the Downtown and Black Creek areas, and individual map services are counter to how the ArcGIS Server API is designed to be used. It is possible to replicate the functionality that exists in SunSpot using map services for each layer, but would increase program complexity and may not work as intended in future versions.

6.3 Recommendations for Future Research

By building and testing SunSpot, steps were taken to further understand how Web technologies can be leveraged to improve the communication of environmental issues to stakeholders and decision makers at the local level. Further iteration in design and functionality is the next step in the development of these tools as only basic decision making functionality was realised in SunSpot. Research on these next steps will involve identifying a balance between application complexity and usability. On one hand, a simple Web-application may be easily accessible to a larger audience, but has limited capability as a decision making tool. On the other hand, if an application becomes too full-featured and complex, it risks excluding non-experts from using it, which is counter to the overall objective. Some questions to be asked include, “is there a way to strike a balance between complexity and ease-of-use?” “How can Web-GIS, SDSS, usability engineering, and new geovisualisation techniques are leveraged to engage non-experts as decision makers without compromising decision making capabilities?” “Should significant features be modularized or be separated as entirely different applications?” The last question is of particular interest as many participant responses discussed in Chapter Five suggested additional functionality for SunSpot. In many of these cases, it is possible that these tools would complement existing tools, while others may be more suited to unique applications with a different focus. Designing a one-size-fits-all Web-SDSS may infeasible when trying to engage non-experts. An increasing trend toward publishing Web-GIS and mapping services for use in other applications can ease this challenge as others can develop useful applications from available components.

While developing accurate solar resource data was not a specific objective of this thesis, the process of building a solar resource database shed light on challenges, namely the lack of available data that may make cost-of-entry for some local governments too high. While some research has investigated the validation of spatial solar resource data, little has been done in terms of determining the significance between simple and complex topographic data (Jakubiec and Reinhart, 2012). It remains unseen if spatial trends in solar potential can be obtained from study areas with access to complex data such as LiDAR topography, and transferred to regions without these data. However, this first requires a more thorough investigation on how much solar resource potential varies across space at different local scales. It may be possible that building 'typologies' may be generated from areas with high quality data and then used to parameterize solar models in areas with limited data. This might be done among areas within a city where data availability varies, or between different cities.

Including links to external websites for local PV suppliers, existing PV installations, local groups interested in solar energy, or links to government websites related to green energy can help support further action in the decision making process. Many of these data were not included in order to distance SunSpot from providing results that provide an absolute measure of feasibility, such as if cost of installation was included. However, encouraging users to explore additional resources can help build a stronger level of understanding and encourage them to possibly take action based on SunSpot's results and the expert advice from a manufacturer or installer.

Developing improved topographic data can help increase the accuracy of the solar resource data produced. In areas where LiDAR is not used to generate a complete topographical representation of the surface (including all features), improving vegetation and rooftop detail is important. Local vegetation can play a significant role in shading as identified in Chapter Five. Areas with little to no representation of vegetation may be returning significantly higher solar radiation values than they should. Detailed rooftop structure data for high density buildings would include roof access, glass roof structures, building climate control equipment, green roof space, and other features that impact local shading or the amount of open space for installing PVs.

Finally, much more can be investigated regarding the accuracy and precision of the solar resource data. While this thesis did not perform any quantitative analysis on the data, it is a significant factor when investigating new methodologies for building solar resource datasets with varying data availability. At the local scale, ground reference data would be the ideal source for comparison as irradiance can be measured over a given period of time for an individual rooftop. By investigating many different types of roof compositions in different parts of a study area, building typologies can be identified and compared to ground reference data. Gathering ground reference data for at least one year from multiple points on multiple rooftops is a considerable and costly amount of work. Reducing the sample size using these typologies would be an ideal way to mitigate this.

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Appendix A:
Workshop material

GEOIDE workshop invitation

University of Waterloo

This letter is an invitation to attend a workshop for the Geoide-funded project "Local Climate Change Visioning Tools and Process for Community Decision-Making". This workshop focuses on the work conducted by Andrew Blakey as part of his Master's degree in the Department of Geography and Environmental Management at the University of Waterloo under the supervision of Professor Robert Feick.

The workshop provides an opportunity for you to explore an interactive web-mapping tool that was developed to visualize variations in urban heat across Toronto neighbourhoods and also compare the solar energy potential of individual buildings within two study areas (main CBD area and Black Creek neighbourhood).

We are interested in developing this software and associated data further to provide better capabilities for exploring the geographic variations in urban heat challenges and small-scale solar energy potential in Toronto. Your feedback, suggestions and input from this workshop will assist us to determine how effective the mapping tools and geospatial visualizations are as aids for exploring, learning and communicating urban heat effects and solar power feasibility as well as their potential utility for operational.

Participation in this study is voluntary. It will involve an interactive computer-based workshop of approximately 90 minutes to take place at the Spatial Decision Support Lab (Environment 2) at the University of Waterloo or another location at your convenience. Two workshops will be held during the last two weeks of November (dates to be confirmed by email). A workshop consists of performing a few tasks along with answering a brief questionnaire. You may decline to participate in any of the tasks or answer any of the survey questions if you so wish. Further, you may decide to withdraw from this study at any time without any negative consequences by advising the researcher.

To enable us to understand better how well the software functions, some aspects of your use of the tool are recorded (the amount that you zoom in on the map, which tools you make use of, etc.). Note that no personal information is recorded in this process and that all information you provide is considered completely confidential. Your name will not appear in any thesis or report resulting from this study, however, with your permission anonymous quotations and anonymous results related to stored user inputs and user interactions with the software may be used. All written information collected from this session will not include personal identifying information and will be kept for a period of two years in a locked location at the University of Waterloo. Digital information will be retained indefinitely on a secure password protected server at the University of Waterloo. Only researchers associated with this project will have access to this information. There are no known or anticipated risks to you as a participant in this study.

If you have any questions regarding this study, or would like additional information to assist you in reaching a decision about participation, please contact me by telephone (519) 888-4567 ext. 35493 or email (rdfeick@uwaterloo.ca).

I would like to assure you that this study has been reviewed and received ethics clearance through the Office of Research Ethics at the University of Waterloo. However, the final decision about participation is yours. If you have any comments or concerns resulting from your participation in this study, please contact Dr. Maureen Nummelin, the Director, Office of Research Ethics, at 1-519-888-4567, Ext. 36005 or maureen.nummelin@uwaterloo.ca.

If you are interested in participating to this study, please contact me by email at rdfeick@uwaterloo.ca.

I very much look forward to seeing you at the workshop and thank you in advance for your assistance.

Yours Sincerely,

Rob Feick

School of Planning

University of Waterloo

Toronto GEOIDE Local Climate Change Geovisualization workshop

Introduction

Climate change has emerged as one of the most pressing challenges confronting Canadian communities. Increasingly, communities are engaged in developing initiatives at local scales (i.e. city, street, building) to adapt to or mitigate this global phenomenon. SunSpot is a Web-mapping application designed to help decision makers and, ultimately, the public explore urban heat island effects and reduce carbon emissions through small scale solar energy generation. The data and tools presented focus on investigating three components: remotely sensed surface temperature, land cover, and modeled solar energy potential. In combination, these data may shed light on local (building-level), neighbourhood-wide, and city-wide opportunities for meeting these criteria.

The primary purpose of this workshop is to evaluate a set of geovisualization options and map-centred tools that have been developed to aid understanding of local effects of climate change and possible adaptation and mitigation options. The secondary purpose is to gather feedback concerning the tools' user interface and overall ease-of-use and relevance to planning practice.

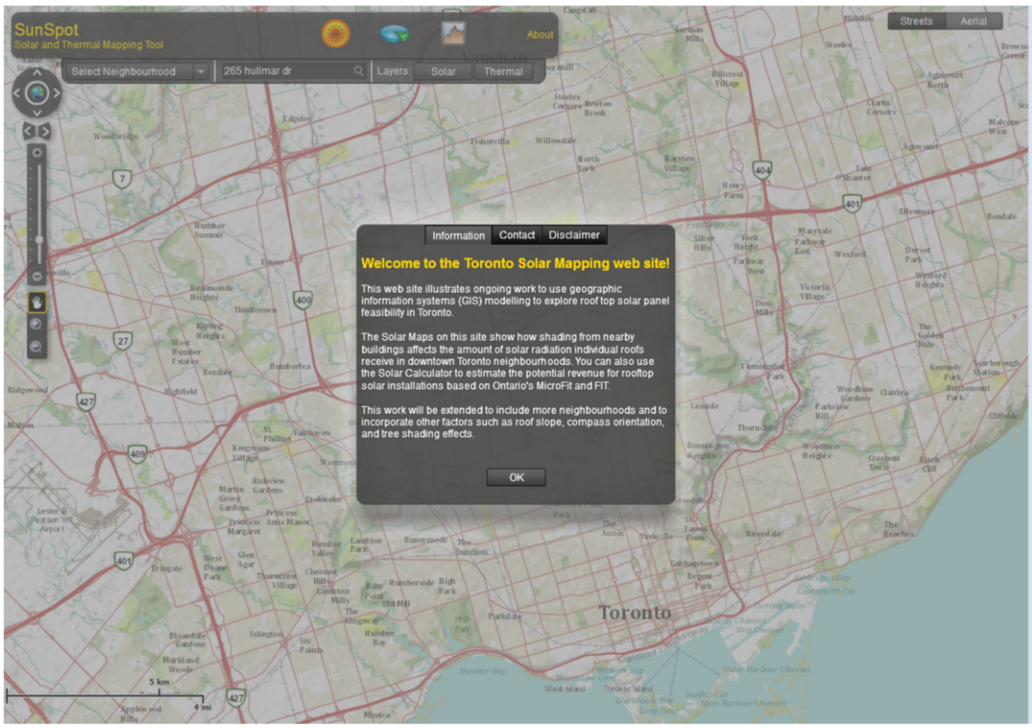
This workshop script provides you with instructions to freely explore SunSpot's features and associated data. You will have opportunities to provide feedback on the extent to which the tool and the mapped data could be useful to you and/or the broader public through short questions that are presented at the end of each section.

Thank you again for your participation.

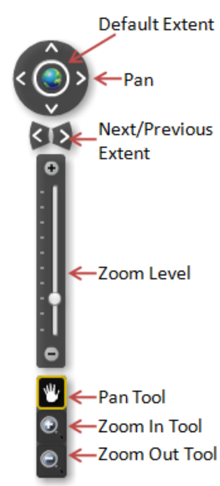
Section 1 – Familiarization with User Interface and Data

This section will help familiarize you with SunSpot's navigational and data viewing tools.

Start Firefox or Internet Explorer and enter http://nipigon.uwaterloo.ca/sunspot to load SunSpot



Hint: Pressing the F11 key will expand your web browser to full-screen view. You can return to normal view at any time by pressing F11.



When finished reading through the introductory information pages, click "I Agree".

Make sure you are familiar with the basic map navigation tools found on the left side of the screen. Also be aware that at any time no other tools are active, you can double click to zoom in as well as hold the left mouse button down to drag and pan the map view.

The 

buttons in the top-right of the map toggle the basemap between a street map and Bing Maps aerial photography. Note that if the Streets basemap is active, building footprints become visible when you are zoomed to a street level scale.

The 

drop down list will pan your view to any of the City's neighbourhoods as well as the Black Creek and Downtown solar study areas. You can also zoom in using the zoom tool (to drag a box around the zoom area), the zoom level slider, or the mouse wheel.

In the 

box, enter an address of your choice (e.g. 30 Hullmar Dr or 200 Wellington St W). A drop-down may appear with multiple address results. Select the one that most closely reflects the desired address.

Selecting the desired address will zoom and pan the map view to that location on the map.

Q1: Are there any comments you would like to make regarding this section?

____

____

Section 2 – Investigating Land Cover and Surface Temperature

Part A – Investigating Land Cover

Variation in land cover can influence a number of factors such as stormwater management, heating and cooling opportunities, and local micro-climate conditions that factor into the urban heat island. These influences are recognized in the Green Development Standard and other City and Provincial initiatives, including efforts to promote green / low albedo roofs and roof-based green energy generation, increase in tree canopy, among others.

The Land cover Chart tool presents the land cover data developed by the City's Urban Forestry Department as simple pie charts that are aggregated for each neighbourhood and parcel in the city. This dataset was originally derived from Quickbird imagery and summarises land cover as 8 classes (e.g. tree canopy, buildings, pavement, etc.) in a raster GIS map layer.

To test this tool, use the 

tool or zoom and pan until most of the downtown region is visible.

Open the Land cover Chart tool by clicking on the second tool icon at the top of the page. Neighbourhood boundaries will now be outlined on the map in dark grey.

Note: Land cover data are presented for selected neighbourhoods when the map is zoomed out and for individual parcels when the map is zoomed in sufficiently. The Select Neighbourhood button will change to Select Parcel to reflect this:

Click 

to enable the tool.

Click on a neighbourhood of your choice. Your selected neighbourhood will be outlined in red and the percent of each land cover class will be displayed as a pie chart .

Repeat steps 3 and 4 times on different neighbourhoods to view variations in the proportions of "green" area (tree canopy and grass) to impervious surfaces (e.g. buildings, roads, and other paved areas).

Next, zoom in on the map until parcel outlines are visible. The Land Cover Chart will change from "Select Neighbourhood" to "Select Parcel".

Click on the "Select Parcel" button and explore the land cover proportions for several parcels of interest to you.

Q2: How useful or helpful could the Land Cover chart tool be for:

Your use:

☐ Not Helpful ☐ Of little Help ☐ Neutral ☐ Somewhat Helpful ☐ Very Helpful

To aid the public's understanding of local land cover – environment linkages:

☐ Not Helpful ☐ Of little Help ☐ Neutral ☐ Somewhat Helpful ☐ Very Helpful

Please explain your answer briefly

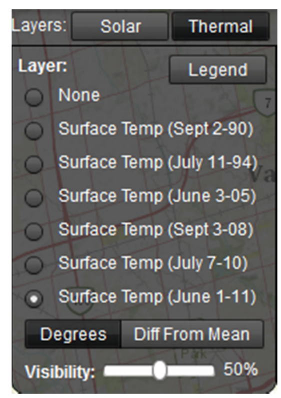
____

____

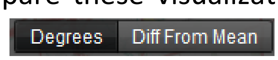
____

Section 2, Part B – Investigating Surface Temperature

This part introduces surface temperature map layers recorded by the Landsat Thematic Mapper satellite and calibrated with ground station data by Matt Maloley of Natural Resources Canada. These map layers show remotely sensed surface temperature readings (C°) for specific days (e.g. Sept. 3, 2008) that vary based on local weather and atmospheric conditions.



It is important to note that while local air temperatures generally vary with surface temperature, many other factors (e.g. nearby land uses, air flows, etc.) also affect local air temperature. Surface temperature can vary more than air temperature especially on sunny days when some surfaces (e.g. asphalt) retain and radiate heat more than others (e.g. lawns).

To permit comparison between layers, a second symbology option was produced that display the differences in surface temperature in terms of standard deviations from the mean temperature recorded across the city. You can compare these visualization alternatives for a particular thermal layer by toggling between the 

buttons.

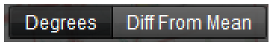
Set the map view to the entire city by clicking on the  map tool.

Click the 

button in the tool bar to display a list of the surface temperature layers.

You can explore different surface temperature layers for by clicking on their corresponding buttons. The Legend window will show you the temperature classes used on the map.

You can interact with these map layers by:

Toggling between 

visualisation options.

Zooming in to an area of your choice to see these differences in greater detail.

Experimenting with the 

basemaps to explore possible context for surface temperature variations.

Adjusting layer transparency may improve legibility.

Q3: Which map representation of surface temperature is most useful or appropriate?

☐ Surface temperature values ☐ Degrees above or below the daily mean temperature

Please explain your answer briefly

____

____

____

Q4: As a communication device, how useful are the Surface temperature data for:

Your use:

☐ Not useful ☐ Of little use ☐ Neutral ☐ Somewhat useful ☐ Very useful

To aid the public's understanding of local land cover – environment linkages:

☐ Not useful ☐ Of little use ☐ Neutral ☐ Somewhat useful ☐ Very useful

Please explain your answer briefly

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You can explore land cover and surface temperature relationships at street and parcel scales by displaying a Thermal layer of your choice and using the Land Cover Chart tool.

Investigate the land cover proportions by clicking on the Land Cover Chart's 

button and selecting parcels of interest.

Toggle between the thermal layers by clicking on their respective radio buttons to investigate possible differences in surface temperature.

Q5: How useful is this approach to exploring surface temperature - land cover relationships?

For your use:

☐ Not useful ☐ Of little use ☐ Neutral ☐ Somewhat useful ☐ Very useful

To aid the public's understanding of local land cover – environment linkages:

☐ Not useful ☐ Of little use ☐ Neutral ☐ Somewhat useful ☐ Very useful

Please explain your answer briefly

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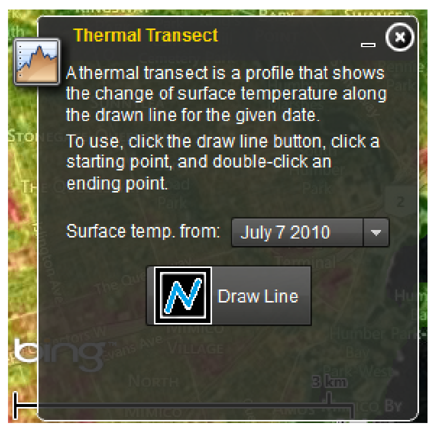
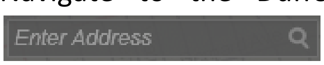
Part C – Using the Thermal Transect Tool



The Thermal Transect tool lets you view how surface temperature varies along a path or transect that you draw on the map. To test this tool, you will navigate to a number of addresses and draw transects across an area of discontinuous land cover types, as well as along a theoretical walking path to view surface temperature variations in graph format.

Navigate to the Dufferin Mall at 1 York Gate Blvd 

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Display the July 7, 2010 surface temperature layer from the 

layers menu.

Open the Thermal Transect tool by clicking on the  icon on the main toolbar.

Set the Transect tool's data source to July 7, 2010.

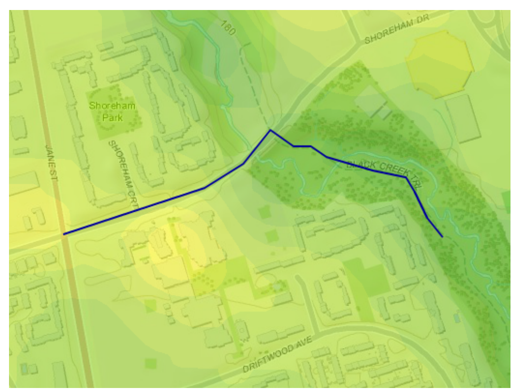
Click on Draw Line to start a new thermal transect line.

Left-click on the map to the east of the Yorkgate Mall to start a line. Finish the line on the west side of Highway 400 by double clicking the mouse in the field just northwest of the Finch Ave. onramps. The line should cross through the mall, a field, Highway 400, and end in a small field to the west of the highway.

A thermal transect graph will appear that is linked to your transect line. This allows you to move the mouse along the top of the graph and see the corresponding location displayed on the map's transect line.

By using a few more mouse clicks, you can create a transect that approximates a "walking route" to a destination. For example, enter 345 Driftwood Ave in the Find Address tool. Zoom out 3 or 4 levels and pan the map until the forested area to the east as well as neighbourhoods to the west are visible.

Select the Draw Line tool and begin drawing a line on the pathway in the forested area north to Shoreham Dr. using single clicks to create vertices in the line at any turns. Continue the transect to Jane St. and double click to complete it.



Move your mouse along the transect graph that appears, taking notice of how the surface temperature changes when transitioning from a forested area to a street.

Q6: How useful or helpful do you believe the surface temperature transect tool could be:

For your use:

☐ Not useful ☐ Of little use ☐ Neutral ☐ Somewhat useful ☐ Very useful

To aid the public's understanding of surface temperature – environment linkages:

☐ Not useful ☐ Of little use ☐ Neutral ☐ Somewhat useful ☐ Very useful

Please explain your answer briefly.

Section 3 - Investigating Solar Resource Data and Potential

This section introduces the solar resource layers that show modeled solar radiation (insolation) that reaches the surface and also illustrates shading effects from topography and nearby buildings. ESRI’s ArcGIS Solar Analyst toolset was used to produce 1 metre resolution raster map layers that show: a) received solar energy (watts per square metre) that is used to estimate returns from rooftop photovoltaic panels and b) hours of sunlight that could potentially be applied to urban agriculture or tree shading analyses.

A variety of data sources were used to create the solar layers including: the City’s Property Data Maps (PDMs) and 3D CAD model, a digital elevation model (DEM), building heights derived from RMSI building footprints, a LiDAR (Light Detection and Ranging) -based surface model built for the Black Creek neighbourhood and monthly atmospheric attenuation data was measured at the University of Toronto at Mississauga’s Meteorlogical Station.

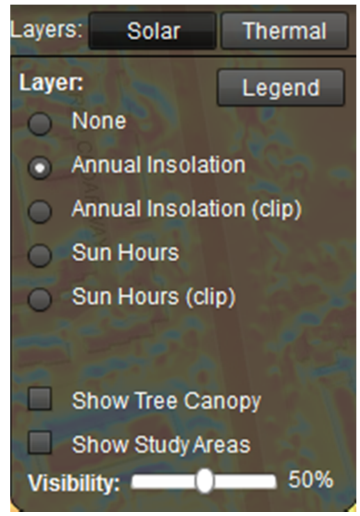
Monthly solar rasters were aggregated for the downtown Toronto and the Black Creek study areas. These raster layers were also clipped to the building outlines to show rooftop insolation only. It is important to note that roof characteristics (e.g. slope, aspect, obstructions, etc.) could only be modeling in the Black Creek area due to limited LiDAR availability. Solar modeling in the downtown area is based on a simpler approach that uses a single height for each roof.

Part A – Visualizing Solar Data

To briefly view shadowing effects of taller buildings, you can select "Downtown Solar" or zoom to a neighbourhood in the core (e.g. Bay Street Corridor).

Open the 

layer menu and toggle between the Annual Insolation and Sun Hours. Areas that receive more solar energy or hours of sunlight (e.g. roofs of tall buildings, south-facing slopes) will appear a dark orange colour, while light- to dark-blue colours signify areas with less solar exposure (e.g. ground or roofs shaded by tall buildings).

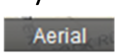


Although suitable LiDAR data were not available to model tree shading for the downtown area, some indication of their effects can be approximated by clicking on the Show Tree Canopy checkbox. The green Tree Canopy layer that is displayed on top of the solar layer was derived from the City's landcover raster data set that was based on QuickBird imagery (i.e. top-down view). For this reason, the solar energy and hours are over-estimated in portions of the City's core with substantial tree coverage.

To view some of the additional capabilities that LiDAR provides in this context, navigate to "265 Hullmar dr" in Black Creek by using the 

tool.

The resolution of the LiDAR data available for the Black Creek study area and time of data collection did allow some tree shading effects to be incorporated into the solar modeling. It also allowed roof slope and aspect to be modeled for residential buildings.

To view the relationship between roof topography and modeled solar energy or hours better, you may want to experiment using the Annual Insolation (clip) or the Sun Hours (clip) layers which only show the solar outputs for building roofs. You may also want to try the 

base map and adjusting the visibility of the solar layer. *Note that due to the nature of aerial photography, rooftops may not line up perfectly with their corresponding solar data.*

Q7: How useful do you believe the solar modelling maps could be for developing strategies or communicating environmental issues (e.g. shading needs, urban agriculture, energy conservation, etc.)?:

Planning / developing strategies:

☐ Not useful ☐ Of little use ☐ Neutral ☐ Somewhat useful ☐ Very useful

Communicating / outreach:

☐ Not useful ☐ Of little use ☐ Neutral ☐ Somewhat useful ☐ Very useful

Please explain your answer briefly.

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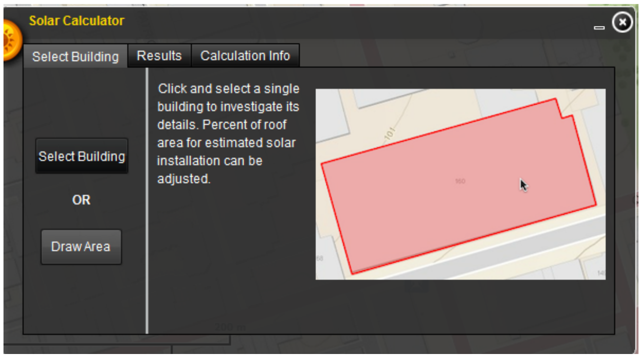
Part B – Investigating Solar Potential

The Ontario Green Energy Act (2010) directed the Ontario Power Authority (OPA) to form a feed-in tariff program to encourage adoption of photovoltaics by consumers. The solar calculator lets you estimate the financial and greenhouse gas benefits of solar panel installations based on solar resource data, roof area, and solar panel placement.

The Solar Calculator has two methods of use. The first method enables the user to select a building and set the percentage of roof that is allocated to solar panels. This method bases solar potential on an roof-wide average of received solar energy. The second method lets a user draw a specific area on the roof where solar panels could best be installed.



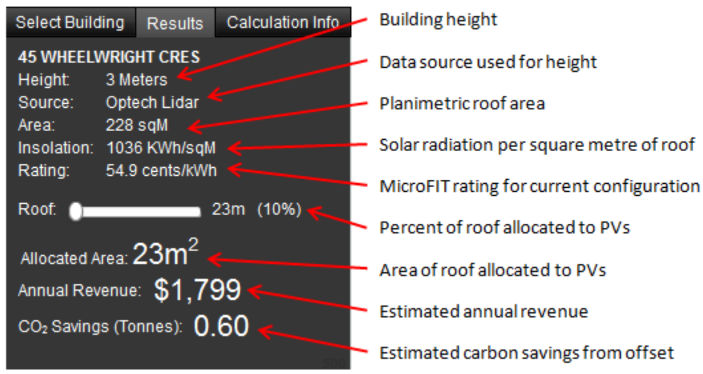
Switch to the Streets basemap and, at least initially, turn off all Solar and Thermal map layers.

Open the Solar Calculator tool by clicking on the sun icon. Note that if you hover your mouse over the "Select Building" or "Draw Area" buttons, a brief description is shown.

Navigate to 32 Hullmar Dr.

Click [Select Building] button in the Solar Calculator tool and then click on the building footprint of 32 Hullmar Dr. After a moment, the tool will automatically switch to the [Results] tab.

The Results tab displays information for the building selected, a slider to define how much of the roof would be fit with solar panels, and the resulting revenue and CO2 savings. The chart displays solar energy in kWh/m^2 throughout the year for the selected building compared to the Toronto average.



Adjust the "Roof %" slider between 10% and 75% and make note of how it affects the calculated values below the slider. Note that typical residential solar systems range between 3-5KW depending on available size. This is generally around $40m^2$

Repeat steps 4 and 6 for one of the buildings neighbouring 32 Hullmar Dr.

Make note of the differences in roof area, solar and carbon estimates, as well as differences in the solar charts.

To compare how roof averages can mask significant differences in solar potential, you can use using the Draw Area method to focus only on the south-facing portion of the same rooftop.

Switch to the Aerial imagery basemap.

Click the "Draw Area" button on the Solar Calculator's "Select Building" tab.

Click one of the south corners of the roof to begin drawing a polygon. Continue sketching the polygon to cover the south face of the roof by clicking at each corner and finally double-clicking at the last corner.

After a moment, the Solar Calculator tool will automatically switch to the results tab, displaying results for the area you have drawn.

Make note of the average insolation in the drawn area (the south face of the roof

Q8: How difficult was it to use and to interpret the Solar Calculator results using the:

Select Building method?

☐ Very difficult ☐ Difficult ☐ Neutral ☐ Easy ☐ Very easy

Draw Area method?

☐ Very difficult ☐ Difficult ☐ Neutral ☐ Easy ☐ Very easy

Q9: Are there specific aspects of the Solar Calculator that need to be improved or changed?

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Q10: Although annual solar model outputs are shown in SunSpot, monthly solar map layers have been prepared and other time increments (e.g. days, weeks) are possible. Please indicate how useful or valuable different frequencies of solar map layers could be:

	Not useful	Of little use	Neutral	Somewhat useful	Very useful
Annual					
Monthly					
Bi-monthly					

Specific days (e.g.summer solstice)					

Please explain your answer briefly.

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Section 4: Scale questions

We are interested in hearing your feedback concerning the usefulness of the tools and map layers at different scales. For each tool or map layer, 3 scales are listed (building, neighbourhood, city). Please check the most appropriate box for each row in the table below.

	Not useful	Of little use	Neutral	Somewhat useful	Very useful
Unclipped Solar Radiation and Sun Hours map layers					
Building					
Neighbourhood					
City-Wide					
Clipped Solar Radiation and Sun Hours map layers (i.e. building roofs only)					
Building					
Neighbourhood					

City-Wide					
Surface Temperature map layers					
Building					
Neighbourhood					
City-Wide					
Land Cover Chart tool					
Building					
Neighbourhood					
City-Wide					
Thermal Transect tool					
Building					
Neighbourhood					
City-Wide					
Solar Calculator tool					
Building					
Neighbourhood					
City-Wide					

Thank you for your participation in this workshop! We will be compiling the results of the feedback you have provided and will send you a summary of results by the end of September. If you have any questions or other comments regarding the tools or map data used in this workshop, feel free to contact us.

Gender:

☐ Male ☐ Female ☐ Prefer not to disclose

Age Group:

☐ 0-18 ☐ 18-24 ☐ 25-34 ☐ 35-44 ☐ 45-54 ☐ 55-64 ☐ 65+ ☐ Prefer not to disclose

How often do you use computer software and the Internet?

☐ Less than once per month ☐ Once Per Month ☐ Once Per Week ☐ Once Per Day ☐ Many times each day

How often do you use computer-based maps (e.g. Google Maps, MapQuest, GIS Software)?

☐ Never ☐ Occasionally ☐ Regularly ☐ Frequently ☐ Very frequently

How familiar are you with global climate change concepts and research?

☐ Not at all ☐ Slightly ☐ Moderately ☐ Very ☐ Extremely

Are you familiar with Toronto's initiatives to mitigate or adapt to local climate change impacts (e.g. Green Development Standard)?

☐ Not at all ☐ Somewhat ☐ Moderately ☐ Very ☐ Extremely

Are you familiar are you with Ontario's incentives to increase renewable energy generation through the Green Energy Act?

☐ Not at all ☐ Slightly ☐ Moderately ☐ Very ☐ Extremely