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Assessing the Influence of Trees on Building Insolation

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Background

My educational foundation, grounded in Geography, has inspired me to consider and question interactions between humans and the environment in many aspects of my postgraduate research. In 2007 I graduated from the University of British Columbia with a Bachelor of Arts in Human Geography, and in 2009 I completed my Masters of Science in Forest Resources Management. As part of my Masters degree I examined remote sensing applications for vegetation management in urban environments. The research presented in this scholarship application describes some of the findings from the third chapter of my thesis, a version of which was recently submitted to *Renewable Energy*. Outcomes related to this research have been adopted in a variety of projects and organizations focused on urban environmental issues including: the Environmental Prediction in Canadian Cities (EPiCC) project, the District of North Vancouver, and University of British Columbia's School of Environmental Health (SOEH). In September 2009 I began my PhD with the goal of further developing applications that utilize remote sensing technologies for providing informative analysis of renewable energy potential in communities in British Columbia.

Introduction

Increased global urbanization is motivating planners worldwide to examine how they capture and utilize the energy required to sustain growing demand. If current trends in urbanization and energy-use continue, the successful development of cities will depend on their ability to negotiate both reductions in energy consumption and the production of new energy from renewable sources. Trees provide a vital natural resource within cities and have a significant impact on both of these urban energy options. Specifically, the strategic placement of shade trees has been demonstrated to increase passive cooling in summer months, with consequent reductions in building energy consumption and indirect benefits from urban heat-island mitigation and air pollution reduction. Trees can also provide added cooling effects on buildings by reducing ambient temperatures through the process of evapotranspiration, as well as impact the radiation available for solar energy technologies.

Concerns over large scale climate warming and a decrease in the supply of fossil fuels are motivating planners to examine the adoption of alternative energy technologies to provide clean and renewable sources of energy. Solar energy technologies, including photovoltaics and solar thermal, have been recognized as viable energy alternatives for urban residential areas due to the ability to retrofit existing buildings with the small scale roof-mounted equipment. While these technologies are already available, bridging the gaps between technological developments and urban planning and decision making strategies are necessary to ensure effective incorporation of solar energy systems into current urban infrastructure. Developing initiatives to strategically manage trees provides a cost effective and sustainable option for helping cities implement solar energy technologies. Nonetheless, energy savings provided by trees can vary greatly between cities and reduction strategies require location specific parameters to provide relevant information. Many of these inter-city differences relate directly to seasonal variations in temperature and sun angles. In many North American cities less energy is expended for space cooling than space heating, and although shade trees reduce cooling-energy use in the summer, cities may notice an increase in winter heating-energy use resulting from the interception of available solar radiation by tree canopies. Nevertheless, further studies in mid-latitude cities suggest that the cooling potential and associated reductions in electricity costs and biogenic emissions provided by shade trees during the summer outweigh any decreases in solar radiation observed in the winter, confirming the utility of shade trees as an effective resource for managing urban energy consumption.

Objective

The objectives of this research were to 1) automate the extraction of structural characteristics of urban residential areas in a mid-latitude North American city using LIDAR as a representation of the city surface and 2) develop a suite of methods to assess the diurnal and seasonal effects of trees on the solar radiation intercepted by residential building rooftops. The study area for this research was the District of North Vancouver in British Columbia, one of seven BC communities working together with SolarBC to explore the potential for generating energy from solar technologies.

Methods

Light detection and ranging (LIDAR) is an active remote sensing device that emits and receives laser pulses. Similar to orthophoto cameras, LIDAR sensors are typically mounted to an aerial platform. By recording the exact location of the sensor and the time it takes each laser pulse to return, a detailed three dimensional dataset is produced over a given area. To extract buildings and trees, and to produce an accurate representation of the city surface, first return, second return, and ground return laser hits generated from the sensor were interpolated to create 1m raster layers. These layers then provided input for GIS-based solar radiation models.

To model solar radiation the *ArcGIS solar analyst* tool was employed to perform calculations based on the hemispherical viewshed algorithm. This algorithm produced viewsheds directed upward based on a digital surface model (DSM), in this case provided from the LIDAR data, and then calculated incoming direct and diffuse radiation from each sky direction. To present a general estimate of the atmospheric condition for different times of the year, the clearness index at 12:00 over a 30 day period surrounding each of the solstices was examined. The clearness index was calculated using measured insolation from tower instrumentation (provided by UBC's micrometeorology lab) and top of atmosphere radiation values. Filtering the trees from the DSM enabled an analysis of the total impact of tree shading on available radiation, while the unfiltered DSM facilitated an analysis of the structural attributes in relation to rooftop received solar radiation. The models were run at hourly intervals during the summer and winter solstices. These dates represent the full range of solar zenith angles for a year and provide maximum and minimum clear sky insolation scenarios. The models were first produced using "clear" atmospheric conditions calculated using the maximum clearness values observed from the tower measurements, and then using "representative" atmospheric conditions calculated from the mean clearness values. Finally, each result was intersected with the LIDAR derived building footprints and both direct and diffuse radiation estimates were extracted for individual dwellings and summarized as an average value for each building rooftop.

Results and Discussion

Some of the key results from this research are displayed in the map featured for this application (figure 1). Emphasis is placed on the seasonal influence of trees as a whole and the diurnal influence of tree height (which represents the most influential structural variable). These results help to quantify the large reduction (an average of 38% - figure 2) in radiation provided by the current state of tree cover in the District of North Vancouver, while also highlighting times of the day (9am and 3pm – figure 3) when radiation is most affected by the structure of trees. The innovative GIS techniques discussed in this research are currently being implemented into the District of North Vancouver's state-of-the-art interactive GIS website to provide citizens with valuable tools for assessing solar energy potential.

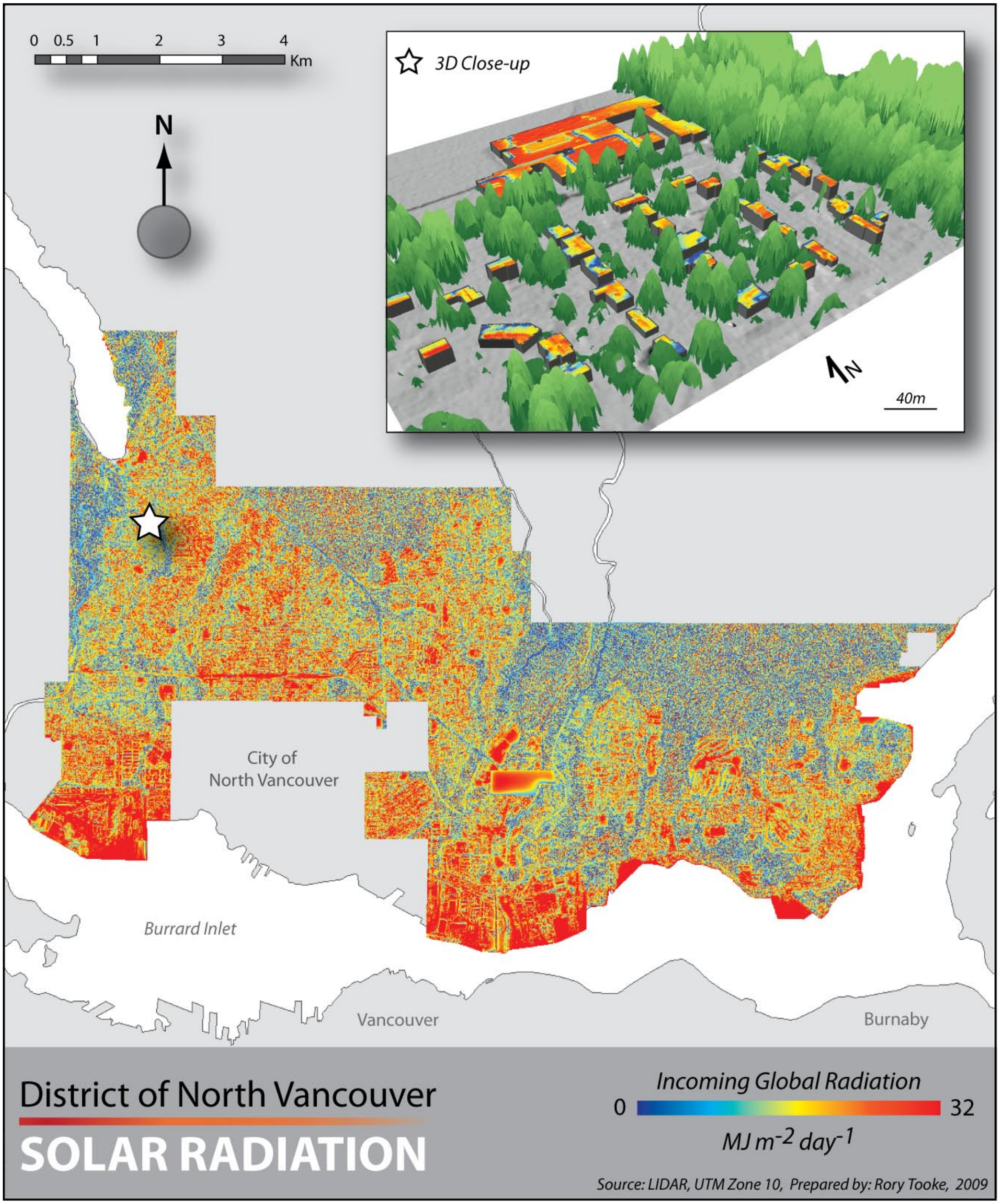

Figure 1. The map above displays the modelled daily global radiation received for the summer solstice. Global radiation, in this case, is a combination of both direct and diffuse radiation. Areas that receive more radiation are shown in red and generally represent low flat areas with few trees in the vicinity. The close-up map provides a three dimensional (3D) view of buildings and trees, and highlights the radiation received for individual building rooftops.

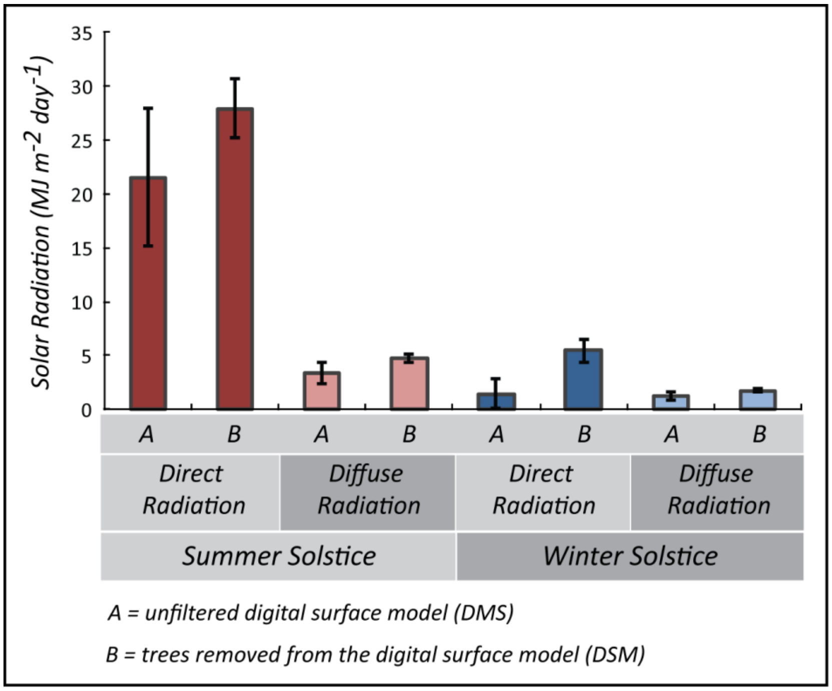

Figure 2. The graph pictured above helps to demonstrate the difference in building insolation as a result of filtering the trees from the input digital surface model. When trees are removed from the DSM, direct and diffuse radiation increases, with the greatest difference observed for winter solstice direct radiation (74%).

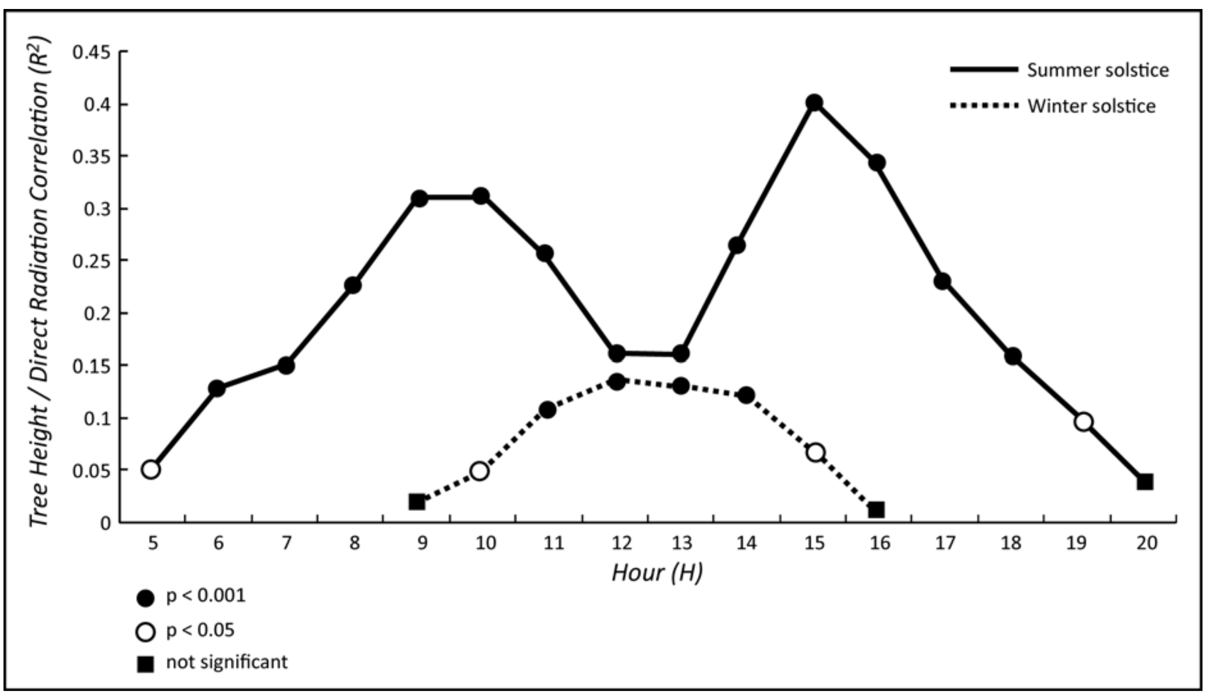

Figure 3. This final graph provides information regarding times of the day when direct radiation is most affected by tree structure. In the research, tree height was demonstrated to be one of the most influential determinants of radiation received on building rooftops. Reviewing this graph suggests that diurnal considerations are important for understanding *vegetation-building insolation* dynamics.