Documenting Local Night Sky Brightness Using Sky Quality Meters: An Interdisciplinary College Capstone Project and a First Step Toward Reducing Light Pollution

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Abstract The advent of inexpensive, hand-held light meters allows science students the opportunity to document night sky brightness in their local communities as a first step toward ultimately reducing local light pollution. We report our preliminary results of one college student's interdisciplinary capstone project documenting sky brightness in the local campus community. The student produced two maps of sky brightness readings in the Morehead, Kentucky, area using the Unihedron Sky Quality Meter (SQM) and the Unihedron Sky Quality Meter with Lens (SQM-L). Typical night sky brightness measurements within town ranged from suburban to city on the Bortle Scale of visual brightness. We end with a discussion of opportunities for future student contributions to this project.

1. Introduction

Light pollution studies provide K–16 students an excellent opportunity to participate in interdisciplinary research projects (Percy 2002; Alvarez del Castillo 2004). Topics in light pollution span a multitude of disciplines: science, technology, environment, economics, society, and culture. As such, documenting and monitoring light pollution makes an exemplary capstone project for graduating college students. Furthermore, light pollution abatement discussions are more effective when based on quantitative arguments and so capstone projects such as these are both important and necessary.

At many colleges and universities, students are required to do a capstone project to complete their education. These are expected to be intensive, active learning projects. At Morehead State University, mathematics and science students are required to complete a directed research project to fulfill the capstone requirement. In mathematics, the capstone research project is adminstered through a three-credit hour course administered over a fifteen-week semester. Students are required to conduct a research investigation, write a formal paper, and give an oral presentation on their work. Within the broader framework of the University's general education standards, the mathematics capstone course has several learning objectives. These include the ability to:

1. locate, select, organize, and present mathematical information in an appropriate manner;

2. communicate mathematical reasoning effectively in both written and spoken forms;

3. use appropriate mathematical language to communicate ideas;

4. think and reason logically by evaluating, analyzing, and synthesizing information;

5. use technology as a tool to help solve non-trivial real-world problems;

6. express problems in multiple representational forms (e.g., graphical, algebraic, physical model);

7. develop a curiosity and appreciation for mathematics as a dynamic, accessible, and essential tool to model particular phenomena in daily life.

This particular list of objectives is specific to Morehead State University (MSU) mathematics students. However, several of these objectives are common to the capstone course in the physical sciences here at MSU. In addition, these objectives are common to most capstone experiences in the disciplines of both mathematics and science at many institutions of higher learning.

Using hand-held light meters to document night sky brightness on the campus and in the surrounding local community effectively addresses most of these learning objectives. For example, documenting night sky brightness quantitatively requires the use of technology (here a hand-held light meter and a GPS device) and mathematics to address the non-trivial, real world problem of light pollution and effectively meets objectives 5 and 7. The presentation of data measurements in terms of both a logarithmic measure in the astronomical magnitude system and plotted as function of geographic location, addresses objectives 4 and 6. Finally, objectives 1 through 3 are met when the student makes the oral and written presentations.

In addition to meeting these specific course goals, this project has strong interdisciplinary aspects. For example, a student should first research natural sources of night sky brightness since "natural" light levels serve as a baseline for comparison with light pollution levels. These studies expose the student to astronomical sources of light and how such sources are quantified. The student should also do some research to put the problem into context and while doing so learns about plant, animal, and human ecology. In addition, the student can examine other aspects of light pollution such as the economic and environmental impact of the wasted energy associated with light pollution.

2. Data collection methods

All sky brightness measurements were obtained using the Unihedron Corporation Sky Quality Meter (SQM) and SQM-L. The SQM has a full cone angle of 84 degrees and the SQM-L has a lens that narrows the full observation cone down to 20 degrees. Both devices have the same sensor; the only difference is the lens. Each device measures sky brightness in visible light (from blue to red) in mag/arcsec^2. Both devices also measure temperature in both °C and °F; however, all photometric measurements are automatically corrected for temperature effects. Previous groups have reported the uncertainty of SQM measurements to be on the order of ±0.2 mag/arcsec^2 (e.g., Smith *et al.* 2008; Cinzano 2005).

Measurements of night sky brightness were made in accordance with the "Globe at Night" protocol (http://www.globeatnight.org/learn_SQM.html). All measurements were made when the sky was free of clouds (as confirmed using current conditions as found on the "Weather Channel" web site) and moonlight. All data collection commenced at least one hour after sunset. The SQM and SQM-L were allowed to reach ambient temperature before any measurements were taken. All measurements were made away from obstructions (buildings, trees, walls) and at least 7.6m away from lighting fixtures. When taking brightness measurements, the student (JW) held the meters at arm's length above her head. At each location, the student took a GPS reading and then obtained a measurement of sky brightness and ambient temperature with both the SQM and the SQM-L. All results were recorded by hand using a flashlight and notebook. Measurements for the main part of town, which includes the university, were taken on the night of January 21, 2009. (On this date, there was no snow cover on the ground.) Readings on the southern side of town and up along the main route (KY 32, which runs north and east from town) were made on April 24, 2009.

3. Sky brightness around Morehead, Kentucky

The city of Morehead (pop. 5,914) is located in Rowan County in northeastern Kentucky. Nestled in the foothills of the central Appalachian Mountains, Morehead is characterized by largely forested, hilly, and highly dissected terrain where elevation ranges between 208m and 404m. Similar (general) geologic patterns are found throughout the area.

Maps of sky brightness can be created using the GPS readings and the mapping and display facilities of Google Earth (Smith *et al.* 2008). This is a good option for those groups interested in simple displays of sky brightness data. In our case, we choose to use a GIS-based mapping approach because we expect that it will ultimately be particularly useful for not only educating people about light pollution patterns and trends in Morehead and Rowan County, but because it provides a framework in which to explore factors that may be contributing to light pollution (e.g., street lights, buildings), to delineate areas that are currently being impacted by light pollution (e.g., wildlife habitat), and to predict how future development may aggravate the problem.

We used ArcMap 9.2 from Environmental Systems Research Institute (ESRI) to create two air photo-based maps showing each device's brightness readings collected within the City of Morehead. In ArcMap, device readings were overlain on a summer 2006 National Agricultural Imagery Program (NAIP) aerial photo obtained from the Kentucky Division of Geographic Information in order to visualize the correspondence between ground locations and each set of sky brightness measurements.

Examination of the SQM map (Figure 1) reveals that night sky brightness within the town itself varies dramatically, from as bright as 12.9 mag/arcsec^2 near the local car dealership to as dark as 20.5 mag/arcsec^2 in steep-sided valleys. Measurements made near commercial venues such as the local strip malls and plazas tended to be among the brightest sites. Shadowing by the surrounding hill sides (e.g., Smith *et al.* 2008) is evident at a number of locations in local "hollows" (i.e., the area between two hills). Sites at the edge of town also have lower readings due to distance effects (e.g., Pike 1976; Berry 1976). In fact, a measurement taken at nearby Cave Run Lake some 20km away benefits from both distance and hillside shielding: average SQM readings at this remote location were 21.7 mag/arcsec^2.

Readings taken with the SQM-L (Figure 2) indicate that the main part of town and campus are in fact quite bright: most readings are significantly brighter than 19 mag/arcsec^2. Using the Sky Brightness Nomogram (http://www.darkskiesawareness.org/img/sky-brightness-nomogram.gif) provided by the International Year of Astronomy's Dark Skies Awareness website, it is clear that most of the town ranks between 6 (bright suburban sky) and almost 8 (city sky) on the Bortle Scale (Bortle 2001)!

A comparison of Figures 1 and 2 reveals a striking difference in meter readings. This is to be expected, given the much larger field of view of the SQM versus the SQM-L. The cone of the SQM is large enough that readings are significantly influenced by street lights, buildings, and trees. Thus, all future measurements will be made using the SQM-L.

4. Summary and future

This student's work effectively documented night sky brightness in Morehead, Kentucky, during the first half of 2009. She presented her work at the state-wide meeting of the Kentucky Association of Physics Teachers in Louisville, Kentucky, on March 7, 2009, to an audience of college faculty and students and high school faculty. Later, in May 2009, she spoke to a local audience of Morehead State University students and faculty at her capstone presentation. Together, these presentations afforded the student meaningful "community engagement" activities.

As the city and county continue to grow, future students will monitor the evolution of light pollution using the Unihedron Sky Quality Meter and create additional maps. The aim is to continue to educate both the campus community and local residents and leaders about light pollution and its negative economical, ecological, and aesthetic effects—with the goal of reducing overall light pollution in the area. Towards this end, both measurements and maps will be shared with appropriate university, business, and government entities—as well as local residents—to help support the development and implementation of more effective and efficient lighting policies throughout the community.

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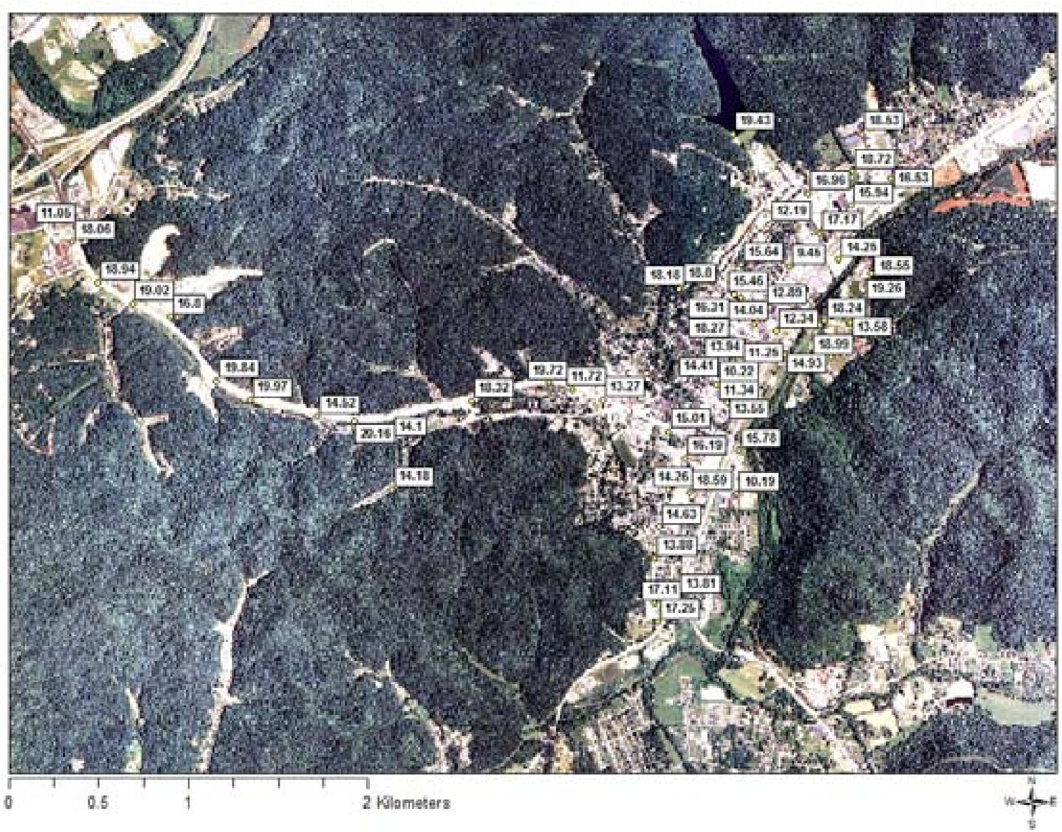

Figure 1. Night sky brightness readings for Morehead, Kentucky, using the first generation Unihedron Sky Quality Meter (SQM) with an 84-degree cone. The readings are in magnitudes per square arc second with an uncertainty of about ±0.2 mag/arcsec^2.

Figure 2. Night sky brightness readings (in magnitudes per square arc second ±0.2 mag/arcsec^2) for Morehead, Kentucky, using the Unihedron SQM-L with a lens that narrows the sampling cone down to 20 degrees.