Journal of Quantitative Spectroscopy & Radiative Transfer 139 (2014) 52–63

Contents lists available at ScienceDirect

Journal of Quantitative Spectroscopy & Radiative Transfer

journal homepage: www.elsevier.com/locate/jqsrt

# Sky brightness levels before and after the creation of the first International Dark Sky Reserve, Mont-Mégantic Observatory, Québec, Canada

Martin Aubé*, Johanne Roby

*Cégep de Sherbrooke, 475, rue du Cégep, Sherbrooke, QC, Canada J1E 4K1*

ARTICLE INFO

*Article history:*
Received 31 August 2013
Received in revised form
23 January 2014
Accepted 28 January 2014
Available online 4 February 2014

*Keywords:*
Light pollution
Sky brightness
Modeling
Aerosol optical depth
Artificial light at night
Second order of scattering
Dark sky reserve
Mont-Mégantic

ABSTRACT

In 2007, the area around the Mont-Mégantic Observatory (MMO) was officially certified by the *International Dark-Sky Association and the Royal Astronomy Association of Canada* as the first International Dark Sky Reserve (IDSR). In order to be able to investigate the impact of Artificial Light at Night on night sky brightness before and after the establishment of the IDSR, we used a heterogeneous artificial sky brightness model including an implicit calculation of 2nd order scattering (ILLUMINA) developed by Martin Aubé's group. This model generates three kinds of outputs: the sky radiance at the given site, observing angle and wavelength and the corresponding contribution and sensitivity maps. The maps allow for the identification of the origin of the sky radiance according to each part of the surrounding territory. For summer clear sky conditions, the results show that replacing light fixtures within a 25 km radius around the MMO with cut-off High Pressure Sodium devices and reducing the total installed radiant power to ~40% of its initial level are very efficient ways of reducing artificial sky brightness. The artificial sky brightness reduction at zenith observed after the establishment of the IDSR was ~50% in the 546 nm mercury spectral line, while the reduction obtained in the 569 nm sodium line was ~30%. A large part of that reduction can be associated to the reduction in radiant power. The contribution and sensitivity maps highlight critical zones where any changes in the lighting infrastructure have the most important impact on sky brightness at the MMO. Contribution and sensitivity maps have been used to analyze the detailed origin of sky brightness reduction. The results of this study are intended to support authorities in the management of their lighting infrastructure with the goal of reducing sky brightness. The results have been shared with MMO officials and are being used as a tool to improve sky quality at the observatory.



## 1. Introduction

Dark sky areas are now increasingly rare in the world and this is due to the constant growth of artificial light at night (ALAN). This phenomenon is largely the result of human activities and its primary sources are street lamps, advertising panels and lighted buildings. Astronomers were the first to point out that dark skies are disappearing when they realized that sky observation was becoming more difficult because of the bright halos caused by ALAN. It is only in the past decade that the multiple negative impacts of ALAN on fauna, flora and human health have been documented more intensively in the literature [1–3].

Artificial light produced by street lights has been identified as one of the major sources of night sky brightness.

* Corresponding author. Tel.: +1 819 564 6350x4146.
*E-mail addresses:* martin.aube@cegepsherbrooke.qc.ca (M. Aubé), johanne.roby@cegepsherbrooke.qc.ca (J. Roby).

http://dx.doi.org/10.1016/j.jqsrt.2014.01.021
0022-4073 

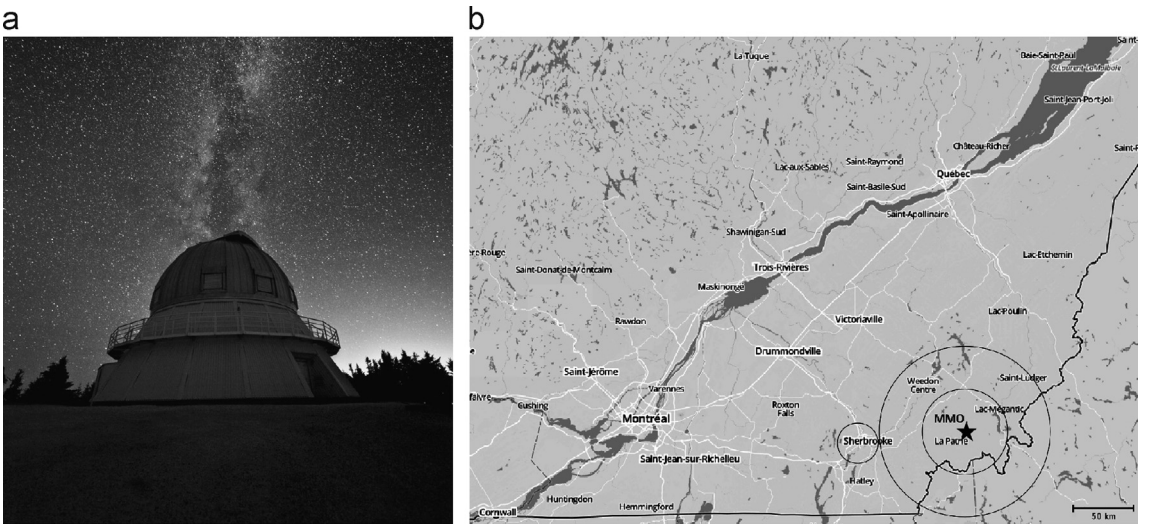


**Fig. 1.** Mont-Mégantic Observatory (MMO) with the Milky Way right above (a) and its location relative to the cities in southern Québec (b). Credits for left pane picture: Guillaume Poulin. The map on right pane has been created with OpenStreetMap©, OpenStreetMap contributors. MMO is identified by the dark star on pane (b).

As such, sky brightness can be reduced by improving their performance. For example, a transition from the Cobrahead model street light, which emits ~6% of its flux upward, to the Helios model, a cut-off street light which emits ~1% of its flux upward, clearly reduces the total amount of light. In fact, the downward flux is largely absorbed by the ground, especially during the summer when there is no snow cover.

In 1978, a professional astronomical observatory located about 1100 m above sea level on top of Mont-Mégantic in the Eastern Townships, Québec (Canada) was inaugurated. The Mont-Mégantic Observatory (MMO) is equipped with a Ritchey–Chrétien telescope whose primary mirror is 1.6 m in diameter, making it the fourth largest in Canada and the largest in eastern North America. It is the best equipped astronomical observatory in Canada [5,6] and is located over 60 km from the closest urban center (Fig. 1). Its mission is to conduct astrophysical research and train young researchers for work in other major observatories around the world, thus exporting expertise from the Observatory. Also, the Observatory develops state-of-the-art instruments that are globally recognized for their high quality.

It is estimated that in 1979, the sky brightness at the summit of the MMO was around 25% higher than the natural sky brightness value. This evaluation was, unfortunately, only made qualitatively by observatory staff members. Despite being located far from major centers, sky brightness at the summit further increased, almost doubling, between 1979 and 1998 (i.e. an increase of ~4% per year). This increase in sky brightness became a real threat to scientific studies and to the basic objectives of the MMO. Furthermore, the research, education and tourism activities in the region of Mont-Mégantic are based primarily on the astronomical observatory; the protection of the night sky is thus crucial for the local population.

Faced with these challenges, it became imperative to stop the growth of artificial lighting in order to reduce sky brightness. ASTROLab, a public outreach center, developed and implemented a light pollution abatement project that included the establishment of an International Dark Sky Reserve (IDSR) covering 5500 square kilometers around the MMO. This regional-scale initiative provided us with the unique opportunity to study the changes in artificial sky brightness parameters before and after the implementation of these protective measures.

In this paper, we will describe how light fixture parameters, properties of urban and rural environments (reflectance, obstacles and topography), wavelength, and atmospheric content may influence the level of sky brightness as a function of the viewing angle. Comparison of artificial sky brightness levels before and after the creation of the IDSR will also be shown. To achieve the level of sensitivity needed for the present study, we used a heterogeneous numerical radiative transfer model [8,9]. The results allow us to represent as faithfully as possible the phenomenon of artificial sky brightness as can be seen from a standing point at any horizontal and vertical viewing angle. In our study, the observer location was set to the MMO.

The model also produces contribution and sensitivity maps, two powerful tools that allow the identification of the origin of the artificial sky brightness and the most efficient ways to act in order to reduce it. By comparing the results for 2005 (before the creation of the IDSR) with the results for 2009 (after the creation of the IDSR) we will be able to monitor the impact of creating the IDSR on artificial sky brightness.

## 2. Methods

### 2.1. Background

#### 2.1.1. The light pollution abatement project

In 2003, after considering several initiatives aiming to address the worsening sky brightness problem, a local public outreach center, ASTROLab, developed an ambitious light pollution abatement project to reduce artificial sky