EXPLORING THE USE OF DRONES TO EVALUATE LIGHT EMISSIONS FROM ONTARIO GREENHOUSES

Benjamin Snow (bsnow@uoguelph.ca)[1], William Lubitz[1], Syeda Tasnim[1], Thomas Graham[2], David Llewellyn[2], Fadi Al-Daoud[3], Andrew Wylie[3]
[1]University of Guelph, School of Engineering [2]University of Guelph, School of Environmental Sciences [3]Ontario Ministry of Agriculture, Food and Rural Affairs

Problem

Concerns about impacts of light pollution from greenhouses are increasing as supplemental lighting becomes more prevalent. Light abatement curtains are commonly used to reduce light emissions from greenhouses. The Townships of Kingsville and Leamington have passed bylaws requiring full closure of curtains when supplemental lighting is in use. This is a challenge for operators because fully closed curtains can interfere with ventilation, complicating regulation of temperature and humidity within the crop canopy. Little quantitative data is available on light emissions from greenhouses or the effectiveness of light abatement curtains in practice.

This study sought to develop methods to quantitatively measure greenhouse light emissions. A Remotely Piloted Aircraft System (RPAS, or "drone") was used with two different sensing methods to explore the practicality of measuring the effectiveness of curtains in decreasing light emittance from operating greenhouses. The project is ongoing, and current results are preliminary and have not yet been subjected to rigorous statistical analysis.

Locations and Materials

The RPAS was flown at night over eight different southern Ontario greenhouses that were growing a range of vegetable crops, and had different cover materials, lighting, and curtains types. To provide anonymity, the greenhouses were assigned letters. Greenhouse H is the Bovey research greenhouse on the University of Guelph campus. The example images shown in this poster are of greenhouse H.

Greenhouse	Cover Material	Curtain Type	Lighting	Crop
A	Triple Poly	LA	HPS	Propagation (empty)
B	Clear Glass	LA	HPS	Cucumbers
C	Clear Glass	Energy	HPS	Tomatoes
D	Clear Glass	Energy	LED	Peppers
E	Clear Glass	LA	LED	Tomatoes
F	Clear Glass	LA	HPS – LED Hybrid	Tomatoes
G	Triple Poly	LA	LED Intercrop	Cucumbers
H (Bovey)	Clear Glass	Energy	HPS	Mostly Empty

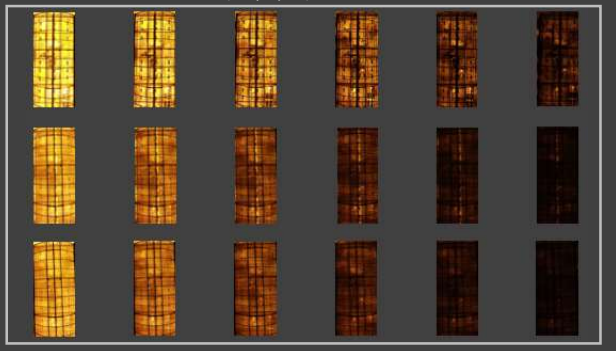
LA = light abatement. HPS = high pressure sodium.

A DJI Matrice 210 RPAS was flown above a representative location at each greenhouse. Curtain opening was varied from 100% (fully retracted) to 0% (fully closed). Sets of images and light intensity were recorded at each curtain setting.

The RPAS carried two downward-looking instruments: a Zenmuse X4S RGB camera and a Sky Quality Meter (SQM) Data Logger (Unihedron, model SQM-LU-DL). Camera settings were 1600 ISO, aperture f2.8, sunlight white balance. The SQM-DU-DL is a field-proven low light sensor designed to measure sky brightness. (Note the SQM was not flown at Greenhouse H.)

Methodology

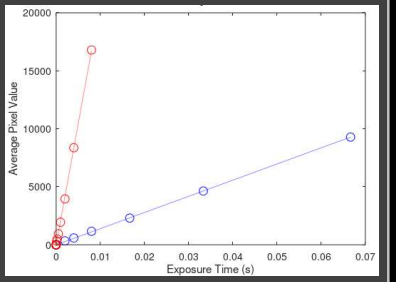
The RPAS was flown at 25 meters above the ground (except at Greenhouse D where the RPAS was flown at 50 meters to maintain line of sight). Sets of photos at increasing exposure times were taken at fixed locations above each greenhouse with the curtains fully closed (0%), and with curtains retracted 5%, 10%, 20%, 50%, and 100% (fully open). The SQM recorded luminance continually.



Example set of images of Greenhouse H with decreasing exposure time from (left to right) and energy curtain positions (top to bottom). Exposure time t decreases from left to right. Energy curtains are fully retracted (100 %), 5% retracted and 0% retracted (closed) in the top, middle, and bottom rows, respectively. Note Greenhouse H has energy curtains, not light abatement curtains.

Raw-format photos were analyzed to quantify relative light emission, expressed as a fraction of light intensity observed with the curtains fully retracted. The analysis steps were:

1. Photos were excluded from analysis if over- or under-exposure criteria were not met.
2. The mean pixel value for a circular analysis region in the center of each remaining image was determined.
3. The mean pixel values were plotted against exposure times. The slope of the lines of best fit are proportional to light intensity. The ratio of the slope at a given curtain position over the slope with curtains fully retracted is theoretically equal to the ratio of light emission at any curtain position over light emission with curtains fully retracted.



Examples of the linear relationship between exposure time and average pixel value for Greenhouse G with curtains 100% retracted (red trace) and curtains 5% retracted (blue trace).

The SQM data was analyzed to quantify the relative light emission at different curtain retraction settings. The fraction of light emission is similarly presented as a ratio of luminance (candelas/m^2) at any curtain position to luminance when curtains are fully retracted.

Acknowledgements

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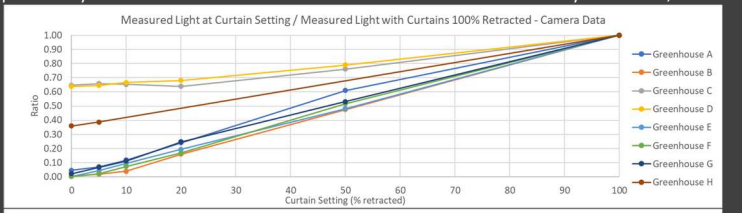
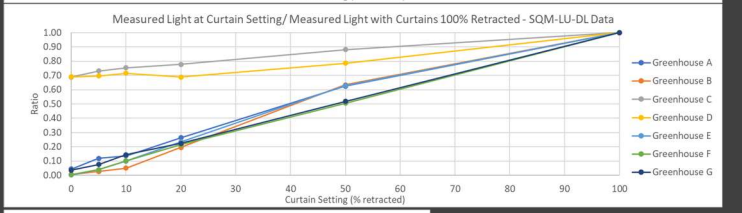
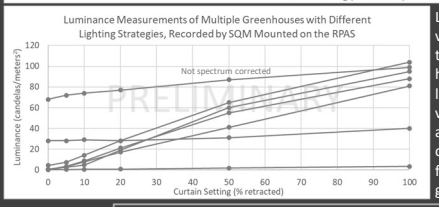
Preliminary Results

The preliminary results below are based on measurements collected in February and March, 2021.







Left: Examples of luminance magnitude (cd/m^2) values recorded by the SQM sensor mounted on the RPAS. The values shown are preliminary and have not been adjusted to account for spectrum, lighting type, altitude, geometric and other variations between sites. This data is presented as an example of the results from the current version of still-evolving methods that are being developed for the determination of light emissions from greenhouses.

Conclusions

1. The fractions of light emission determined from the camera and from the SQM-LU-DL usually gave similar results – this illustrates the potential suitability of RPAS-based methods for evaluating relative light emission for a wide array of commercial greenhouse environments and light pollution abatement conditions.
2. The preliminary results suggest that, with further refinement, these methods based on RPAS observations have potential for quantifying skyward greenhouse light emissions.
3. It is currently too early in the development of these methods to make specific conclusions about the impacts of different curtain types, curtain opening settings, lighting methods, crops, or operational factors on nighttime greenhouse light emissions.

Future Work

The methods for conducting the RPAS measurements continue to be refined. More case studies will be evaluated in the 2021-2022 supplemental lighting season at different commercial greenhouses in the vegetable, floral, and cannabis sectors. Light spectrum information from the camera data will be examined. Statistical methods will be used to determine overall relationships between greenhouse parameters and light emissions. Laboratory tests will be conducted to determine the light transmission properties of different greenhouse cover materials, energy curtains, and light abatement materials. Crop production trials (tomatoes) will be conducted to study the impact of different supplemental lighting and light abatement protocols on greenhouse energy balance, crop microclimate, plant growth and plant health.