Measuring and Monitoring Darkness at 10,000 feet

Measuring a darkness baseline for new developments near the Rothney Astrophysical Observatory

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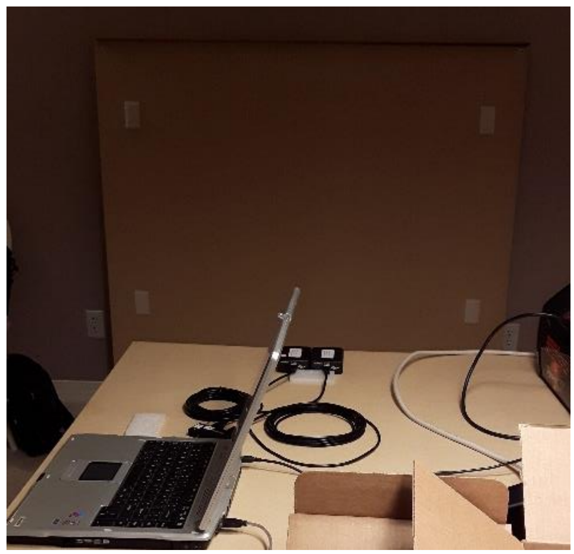
Abstract: Because of its dark sky location and wide range of telescopes and detectors, the Rothney Astrophysical Observatory (RAO) is the top University operated observatory in Canada. The growth of Calgary continues, and two major construction projects close to the RAO will impact the sky darkness at night; the completion of a Ring Road highway, and a new community being built in phases (for more info see oral 4 in session 4). This study is an attempt to measure the current darkness of the areas these projects will occupy when completed, using SQMs mounted to a light wing aircraft flown 2,000 meters above the ground.

1) SQM testing and configuration

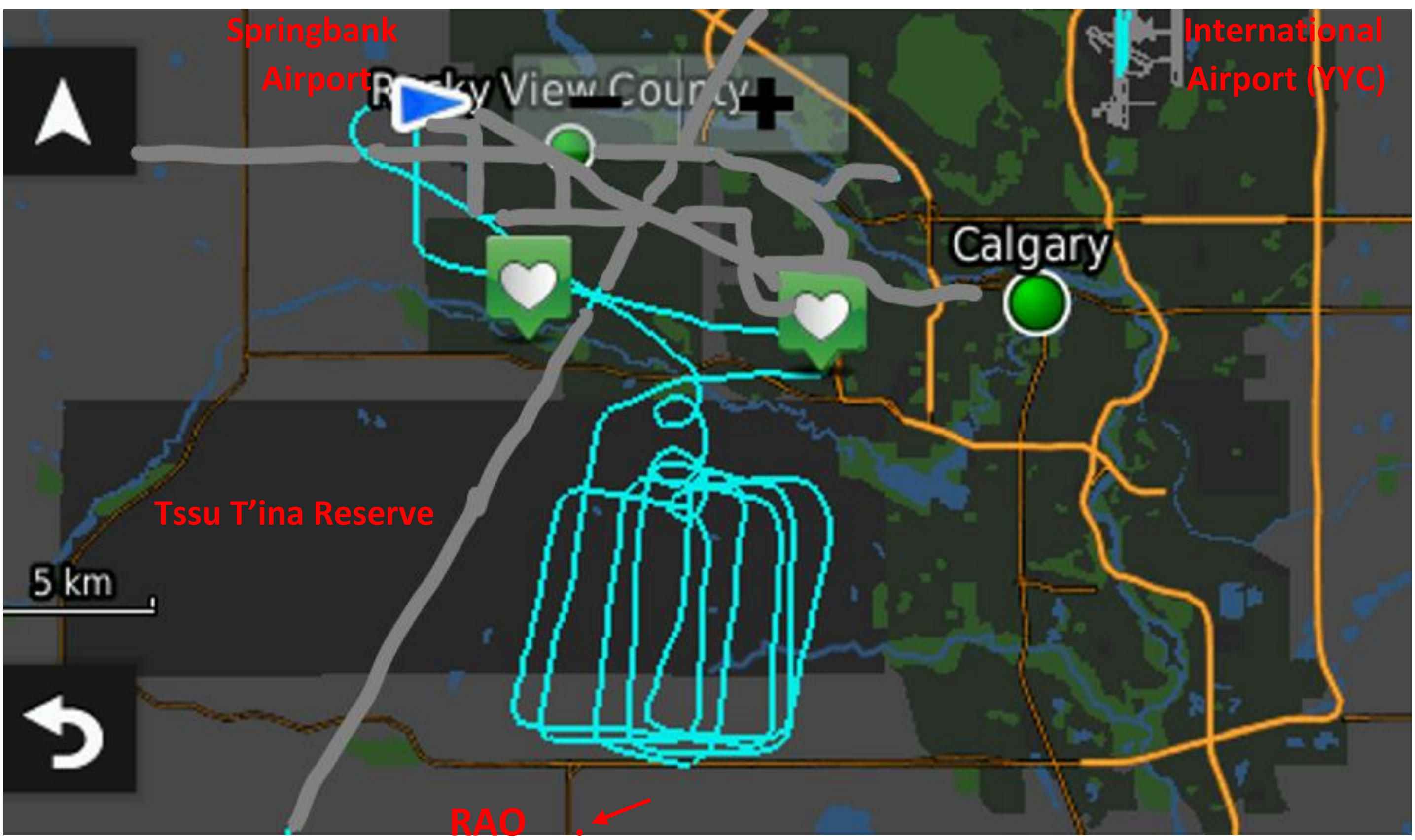


The two SQMs were subjected to the same controlled dark-light conditions for many hours in the laboratory, with the same computer used in-flight. The Zenith SQM consistently produced readings that were lower than the Nadir SQM by 0.14 mag/arcsec^2 (eg. 22.34 mpsas versus 22.48 mpsas). To correctly interpret the in-flight data, an offset of this amount ***needs to be added to the Zenith SQM measurements***.

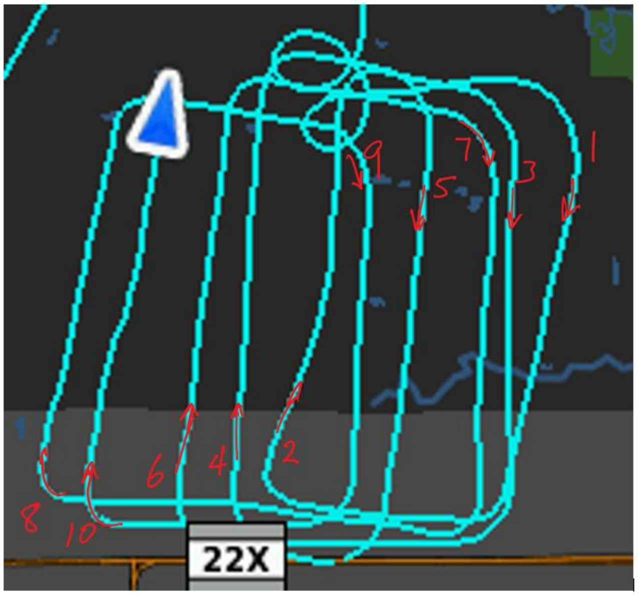
Note that the field-of-view of the SQMs is a cone with approximately 20 degrees opening angle.

SQMs mounted on the most vertical part of the fuselage, one pointing to the Zenith, the other to the Nadir. Note that the SQMs are on the right side of the plane, which blocks the light coming from the left side of the plane. The SQMs only need USB connections to reach the computer which is inside the cockpit.

2) Flight Path and Sky Conditions



Screenshot from a Garmin nuvi 2559LMT carried on the plane showing the path of the SQMs over southwest Calgary starting and ending at the Springbank Airport (magenta line).   The plane was flown in three tight spirals to gain the required altitude. The location of the RAO is the red dot indicated by the arrow.

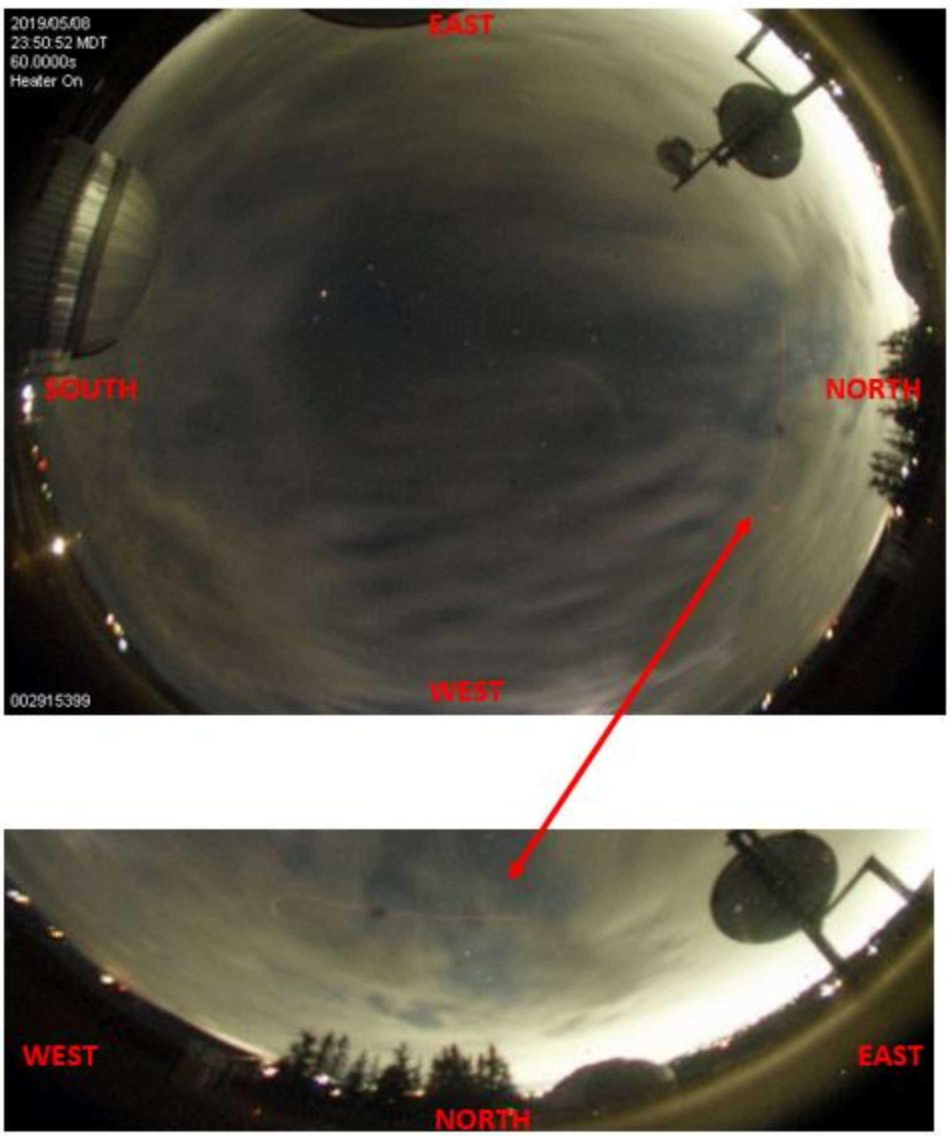


Sequentially numbered passes of the SQMs 2000 meters above the ground (10,000 ft above sea level).

Odd numbers correspond to a southward plane direction (SQMs are shaded from the city by the fuselage).

Even numbers correspond to a northward plane direction (SQMs are on the city side of the fuselage).

The general flight plan was to complete consecutive rectangular passes with a general drift away from the city, towards the west.



The AllSky camera at the RAO captured some of the flight path of the plane in its 60 second exposure images (note the red streak indicated by the arrow – the image below is a crop of the original image above, reoriented east-west).

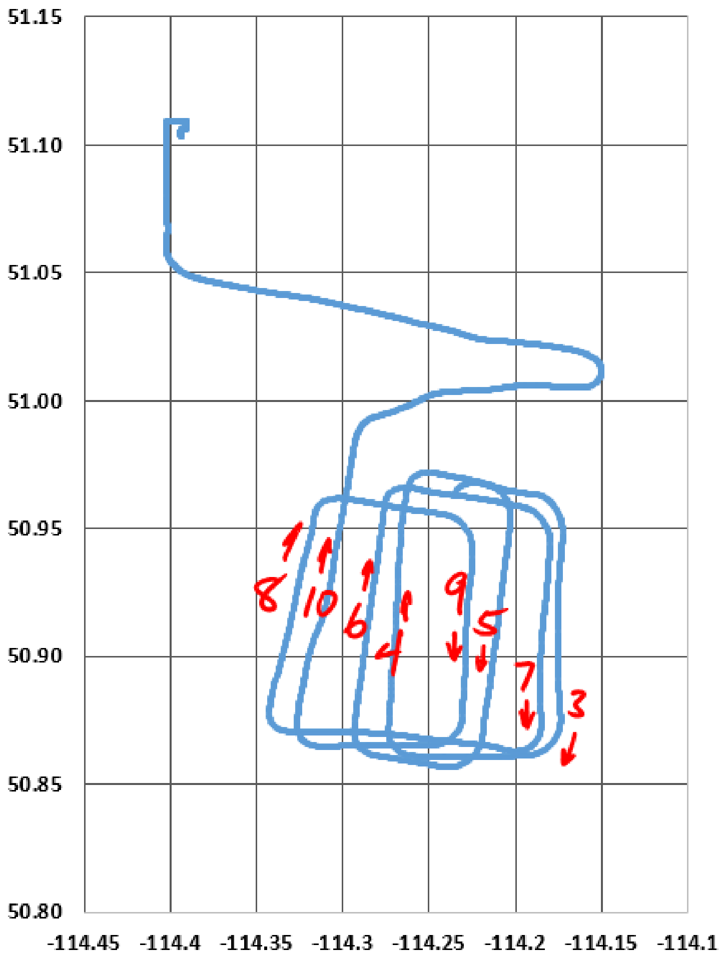
This particular image captures the plane turning northward to path 10 (see the figure above). Path 6 and 8 were also seen by the camera.

The skyglow from Calgary is visible to the NE because of the thin cloud cover which persisted above the SQMs on the plane. Stars can be seen over the transient cloud layer.

The Moon was in ~1st Quarter phase and was very low in the western sky over the ~1 hour of data acquisition (its glow in the clouds can be seen in this AllSky image).

As indicated by the time stamp, this image was recorded close to 10 minutes before midnight on May 08, 2019.

4) Fenix data

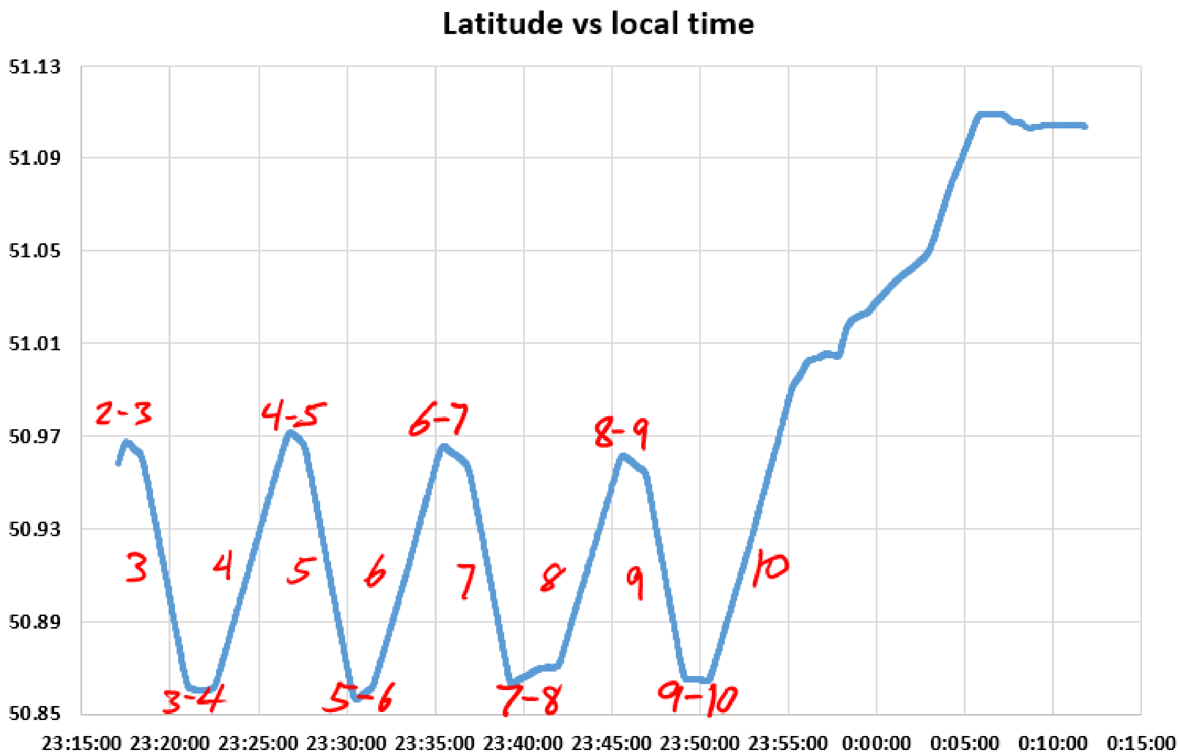


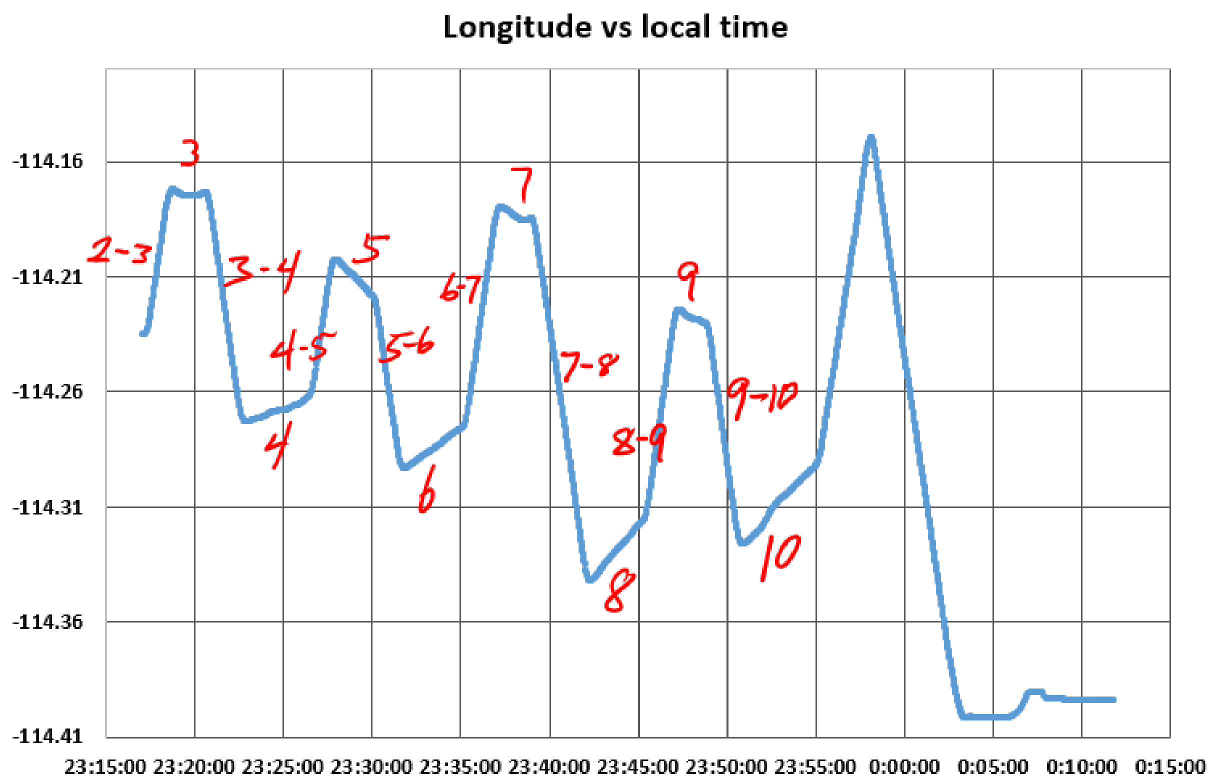
This is data recorded by the Garmin Fenix watch. Latitude, Longitude, Altitude, and Speed, are recorded along with the local time.

This allows the position of the plane to be correlated with the SQM data taken at the same time.

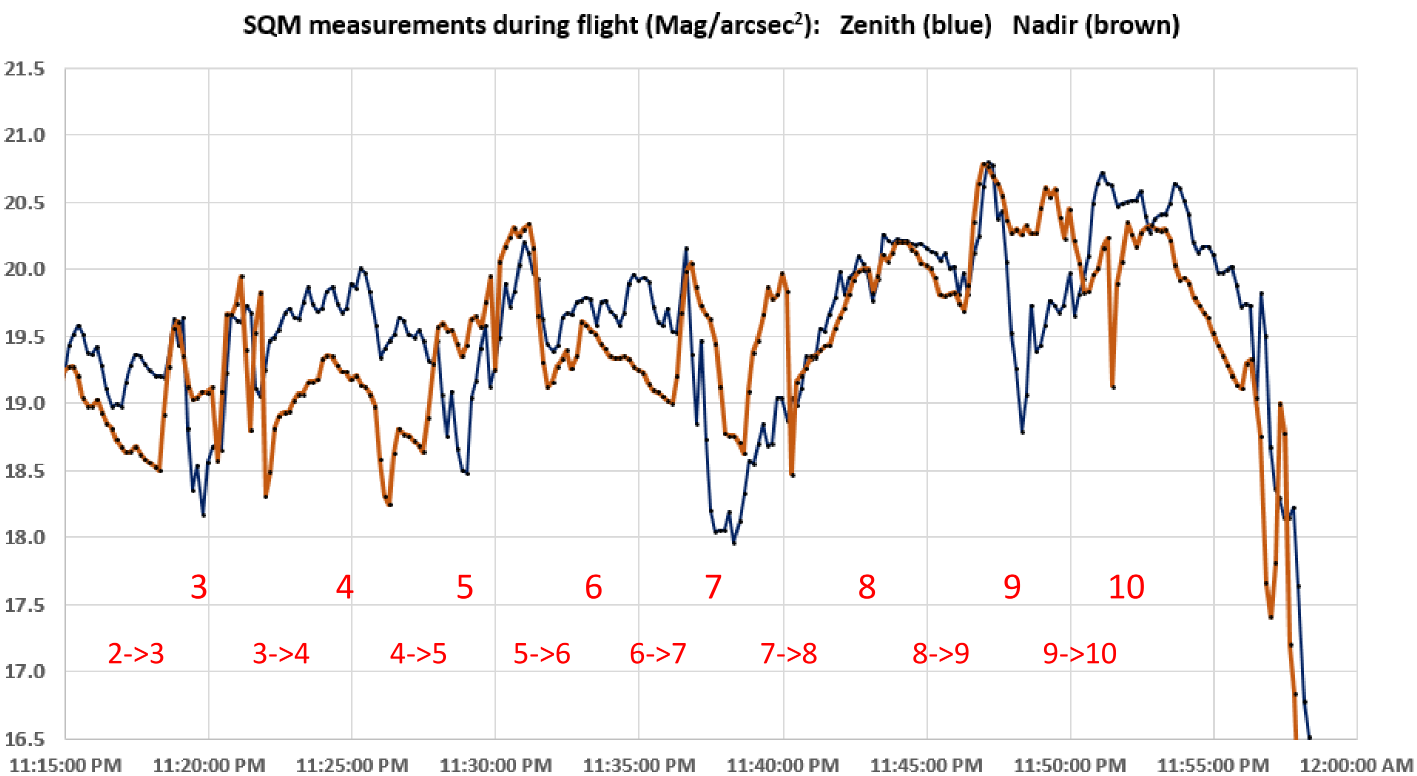
The Fenix was activated late, and data from passes 1 and 2 were missed. The passes shown in the figure above are reproduced in this plot.

Plots of the Latitude and Longitude of the plane as a function of local time are shown below. Indicated in these plots are the locations of the plane using the numbered plane passes described in the corresponding Lat/Long plots.





5) SQM data



These are the measurements recorded by the Zenith and Nadir SQMs for the time period corresponding to the Fenix plane positions. As described above, the Zenith data has been corrected by adding 0.14 mag/arcsec^2 . Because SQMs use magnitude related units, the larger the number the darker the conditions.

6) Observations and Conclusions

In an attempt to look for trends in the SQM data that might correlate to the direction of travel of the plane, the red numbers in the above plot correspond to the passes indicated in the previous Garmin plots. Although the two curves do not follow each other exactly over time, for the most part their trends are similar. The two most general observations are:

1) as the plane moves away from the city, the sky above and below gets darker;
   the ground darkens from ~18.7 to ~ 20.1, and the sky darkens from ~19.2 to ~20.5.
2) the sky over the plane is darker than, or as dark as, the ground below (except for a few occurrences).

Point 1 is expected as the illumination around the plane decreases as one moves farther from the city lights. As to whether point 2 is expected or not, one needs to consider how the sky and ground are illuminated, and how that illumination is reflected into the SQMs. Note that during the time span being examined in this study the plane is over essentially undeveloped land (the land upon which cars and many homes will reside in future). So to 'first order', it is reasonable that the sky above the plane, and the ground below the plane, should be equally dark (neglecting the affects of clouds and Moon).

It is interesting that in every case where the sky over the plane is brighter than the ground below (brown curve is above the blue curve) the plane is moving southward (passes 3, 5, 7, 9). Additionally, when the opposite happens and the sky is darker than the ground (blue curve is above the brown curve), the plane is generally moving northward (passes 4, 6, and 10).

This seems to suggest that because the SQMs are mounted to a particular side of the plane, and that side of the plane is sometimes facing the city and sometimes facing away from the city, that the relative amount of light seen above and below the plane are affected. But as the SQM field of view is relatively small, and the SQMs were carefully pointed opposite each other (and the Moon was very low in the west, far away from the view of the SQMs), this observation remains unexplained. When this experiment is repeated in future, it would be wise to have a pair of SQMs on both sides of the plane.

There is a fairly large span of time (about 7 minutes) where the sky and ground are equally dark even though the plane travels almost a full circle (west then north then east following 7->8 then 8 the 8->9). The readings from both SQMs change from 19.0 to 20.7 which is a significant darkening. As the AllSky camera images show, there was a variable cloud layer about which undoubtedly affected the data. This layer thinned as the data run unfolded, so perhaps some sort of cloud effect subsided during this 7 minutes and the SQMs equalized, and with the plane fuselage blocking the city lights the SQMs gave their darkest readings of the whole run.

With regard to the original goal of this experiment, to measure a darkness baseline from which the affects of future development can be compared, the average reading over the entire 40 minute span (passes 3 through 10) is ~19.4. However, considering the trend toward darker and darker measurements as the clouds thinned and the Moon decreased in altitude, the reading of 20.7 as recorded by both SQMs at the same time could be considered the 'gold standard'.