A Study of the Dark Skies of the Malvern Hills AONB in the Winter of 2012/13

by

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malvernhills
Area of Outstanding Natural Beauty

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1. Context and Background to the Report.

The Malvern Hills Area of Outstanding Natural Beauty (MHAONB) has a number of advisory notes and guidelines for building and green energy projects, appropriate to its AONB status. There is also a tranquillity map of the area compiled by Campaign to Protect Rural England (CPRE).

This report describes a dark sky survey of the Malvern Hills AONB completed in Winter 2012. This provides the material for advisory control on lighting at night to maintain the night-time dark environment particularly with the benefit of the visibility of starry skies.

There is an increasing awareness of the problems of light pollution throughout the UK. Despite the Parliamentary Science and Technology Committee report on light pollution of 2003, very little has been done to control it. The equivalent of over a power station of electricity is effectively thrown to the sky in the UK due to inappropriate lighting.

Very few of the younger generation have ever seen the Milky Way. The sight of the stars above used to be an inspiration to young people to pursue a career in science and engineering, which is now denied to most of us due to light pollution. The ultimate area of outstanding natural beauty and area of special scientific interest is the hemisphere above, and yet it has no protection in law. Better lighting control can have a very significant reduction of light pollution to the sky, and if done nationally with conviction, it should be possible to observe the Milky Way in many suburban areas again. This is particularly relevant in the Malvern Hills AONB.

There still are parts of the country with reasonably good dark skies, and it is important that these are maintained and encouraged. Several areas in the country, including some National Parks, have applied for International Dark Sky status from the International Dark Sky Association (http://www.darksky.org/). This requires night-time illumination to be restricted, and night sky viewing facilities to be provided, and this encourages dark sky tourism. There are several areas in the country that have applied successfully. These include Galloway National Park and Exmoor National Park. The first step to any consideration of dark sky sustainability or preservation, is a dark sky survey. The results of this survey can be used for any future proposal and at least a lighting control guideline.

The intention is to maintain the tranquillity of the dark environment and also to promote an interest by the public in the night sky. For that we need to restrict outside lighting to only pointing downwards, with nothing near the horizontal or above. Fortunately the only major towns with large amounts of street lighting are Malvern and Ledbury, and the Malvern Hills themselves form a partial natural light blocking barrier for part of the area.

The data shows the geographical variation, temporal variation, and angular distribution of the darkest period night sky brightness of the Malvern Hills AONB, from September till December of 2012.

2. Summary of the Methodology

Dark sky readings were taken once a month from September through to December, close to midnight on the clearest of nights when the moon was well below the horizon. Fortunately there was one night each month when all these conditions were met. That isn't always the case.

The first set of readings was done over 40 locations throughout the AONB, and a few just outside. Subsequently data was taken from just those locations where there is a significant clear horizon in several directions which were the sites of all sky imaging over a few nights. Readings were taken using a Unihedron Sky Quality Meter (SQM) type L (lensed). (http://www.unihedron.com/projects/darksky/).

All were from roadside locations. Samples were taken repeatedly holding the metre vertically out of the window. Once the readings settled to consistency within the accepted error of the meter, this was taken as the value. The whole area had to be surveyed in a few hours so as to have the same weather conditions throughout. On some occasions the survey was not complete due to changing weather. The list of locations is given in the data.

On the consecutive dark nights on one month, a series of all sky images were also taken using a fisheye lens camera mounted vertically on the top of the car, from those few locations that have horizon to horizon views in most directions. These were later analysed in intensity profile from East horizon through zenith to West horizon, and from South horizon through zenith to the north horizon and calibrated against the meter readings. One set of meter readings were taken at 45° angles to the zenith north south east and west to coordinate with the photometry plots. Month-to-month temporal zenith photometry variation for these locations was also plotted.

A full description is given in the appendices.

3. Summary of Results

The results are presented in three different forms.

A. An overhead sky brightness set for over 40 locations set out as a colour-coded and photometry value grid covering the whole AONB.

B. A month-to-month sky brightness variation plot for the selected locations.

C. A series of all sky images from selected locations with good views to the horizon including horizon through zenith to horizon. East West and South North photometry profile plots.

The reference letters above refer to the section of the Full Technical Report in Appendix C.

The sky brightness varies little or the whole AONB with the exception of close to and in the towns and within the immediate area of all streetlights, including villages. Looking at the AONB divided into 1 km squares: the darkest regions are on the extreme west, North West and South East of the AONB; these being furthest from areas of high density street lighting and other light sources including external industrial security lighting and illuminated sports pitches.

The darkness of the sky is very much dependent on local atmospheric conditions at the time, these can vary over a few minutes. Heavy rain followed by a clear spell always produces darker readings due to removal of aerosol content. Increased water droplet content has the same effect, especially at dew point asses in the case of winter months when the temperature is zero or below, but this reduces visibility of the stars at the same time. Significantly darker readings were obtained in January and February on few brief occasions. This is common experience over recent years.

The presence of the Milky Way overhead affected the readings, even in central Malvern from Malvern Link common. It is overhead at the darkest time of the night in the autumn and significantly away from the zenith in late winter. In the months after December there was no opportunity to take a complete set of location dark sky readings. Then they were just limited to one site.

The sky brightness away from the immediate street lights, falls with distance over several kilometres from Malvern and Ledbury. The Malvern Hills themselves form a natural barrier to the west of Malvern but only at very low angles to the horizontal. Most of the remaining light pollution is from towns further away across the Severn Valley. The increase from the zenith to the high-rise in is at least 300% in specific directions according to location due to distance relighting. The natural background level vertically is from Birmingham and Bristol and other distant cities.

The Western horizon towards Wales is very significantly darker than that in any other direction. There is a variation in light pollution from centre to the edge of Malvern taking measurements from the commons. This is consistent with the extent of surrounding street lighting which is one-sided on the edge of towns.

More details are given in Appendix C, with the data in Appendices E and F.

4. Recommendations.

Atmospheric scattering by suspended particles of water droplets and dust is mostly towards the horizontal in the direction of the light and very little at right angles. That is why the brightness is so great towards the horizontal. Light close to the horizon is serving no purpose whatsoever. By restricting light from all outside luminaires to downwards to within 60° of the horizontal, the reduction in sky glow is considerable. This is also particularly true in the opposite direction to the luminaires where backscatter is responsible for the sky glow.

Shallow bowl luminaires allow light towards the horizontal while flat glass prevents it entirely.

Included in the Appendix B is a series of diagrams and explanations from my advisory note on light pollution and my papers relating to the modelling of street light design and its effect on the night sky.

5. Further work

This report should form the basis of a practical outside lighting guide for the Malvern Hills AONB. It can also be used to qualify the area for a dark sky status with the International Dark Sky Association. Although not large enough or remote enough from conurbations to qualify as a truly dark skies area, it does offer the opportunity for the general public to see the dark skies. A public area accessible at night with parking facilities would be required and an ordinance to preserve the darkness of the area.

Technical Appendices:

A. About Dr Chris Baddiley

My background is as a theoretical and practical physicist in infrared photometry and predictive modelling of infrared camera performance. I also hold a doctorate in astrophysics and have been running courses and giving public lectures for much of my life. I recently built an observatory with separate control room at my house at the edge of the AONB.

In my spare time, very many years ago, I decided to write a mathematical model relating specific street-light designs from their photometry data, to the sky glow they caused on the sky. At the time, the lighting industry was introducing shallow bowl luminaires, claiming they were less light polluting than flat glass fully downward pointing designs. Outside of the lighting industry it was felt that this was incorrect. I felt it was necessary to do proper mathematical modelling analysis. In fact the differences are extremely great. I have shown how many fully downward control lighting can reduce sky glow by a factor of 10 at least from other types. This work led to me writing a guideline for the lighting industry published by Institute of Lighting Engineers (now ILP), and also a number of papers presented at international conferences. I received the Galileo award by the International Dark Sky Association for this work in 2008. I was also a key ‘presenting witness’ providing evidence to the Parliamentary Science and Technology Committee investigation into light pollution in 2003. This resulted in it being included in the Clean Neighbourhoods Act that followed.

My findings have been accepted and adopted by the Highways Agency for some time, who are in 2013 now redrafting their policy to maintain flat glass fully downward lighting on motorways, in the face of pressure from the European lighting industry to have this relaxed. It is also essential for rural environments, such as rural roundabouts, which was adopted by the British Standards on road lighting many years ago as a result of my contributions. CPRE recognise the importance of maintaining the tranquillity of the dark rural landscape, and avoiding the problem of shallow bowl luminaires which can be seen over great distances.

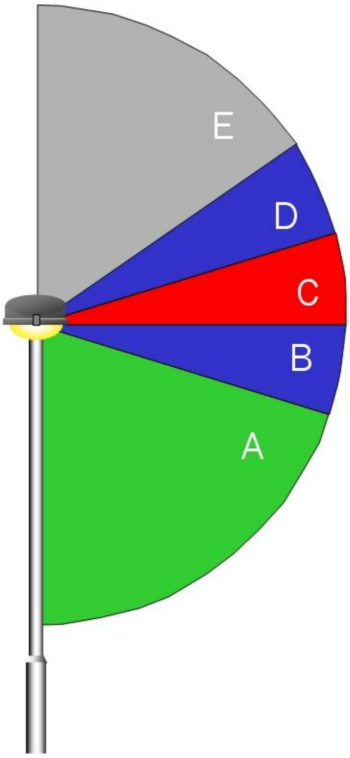
I have been monitoring the sky darkness at my observatory in Mathon since 2008 and also at my previous location in Malvern, and have amassed much data. I have compared these with other surveys and also my own modelling. I'm frequently consulted on such matters.

B. Advice concerning outside lighting (ILP guideline)

Diagram to show relative impact of a luminaire's output contribution to skyglow.

E, 100-180° Critical area for skyglow experience from within urban and all areas but proportionally less impact to rural areas.

D, 95-100° Significant contributor to skyglow, especially in rural areas where it is most aerosol dependent. Less likely to be obstructed.



C, 90-95° Critical zone for skyglow and obtrusion seen at tens of km (in rural areas) where it is strongly dependent on aerosol scattering.

B, 85-90° Significant contributor to skyglow seen at a distance through reflection but reflected light more likely to be obstructed by buildings, trees and topography.

A, 0-85° Ideal light distribution .

To minimise skyglow in the countryside :-

- All lighting should be shielded from horizontal view.
- The reduction in skyglow by universally adopting full horizontal cutoff lighting in all areas outside of town centres can be a factor of 3 to 5 according to elevation and distance of view.
- Shallow bowls can cause more skyglow than equivalent Full Cut Offs (FCO), and are visually more obtrusive. They should not be used in open areas and should be restricted to town centres.
- All measures are needed, such as dimming, as is now being tried, and switching off when not necessary.
- Private Finance Initiatives (PFI) are available for improved quality lighting. But there is more and more lighting for town centres, new housing and amenities.
- Using FCOs alone may not reduce sky glow sufficiently, against the growing amount of lighting in the UK

C. Full Technical Report

a. Introduction

This report provides dark sky data from all over the Malvern Hills AONB, analysed and presented in an in-depth comprehensive manner. It shows the variation in readings from location to location and also the variation from one month to the next under similar dark sky conditions. Considerable variation across the sky was measured from each location which has inferences on the source and nature. The data and conclusions can be used to take whatever steps necessary to maintain the tranquillity and darkness of the night-time rural environment for the enjoyment of the public.

b. Data gathering

Readings were taken once a month on the darkest clearest night in late 2012, with the moon well below the horizon, from about 10:30 PM to 1:00 AM, when the sun is at the lowest below the North horizon. Fortunately during the period of data readings from September to December there was at least one night each month meeting these conditions. This is not always so. On one occasion, the readings were taken in mist/fog for comparison. All locations were by the road side covering much of the area of the AONB. A few locations were just outside of the Malvern Hills AONB, mostly Malvern, for comparison.

The readings were taken using an L type sky quality meter (SQM) by Unihedron. This has become the standard for most dark sky surveys . Readings were taken holding it vertically out of the car window, in locations where no visible lighting was in the area. This was repeated a number of times until the values settled to consistency , within the accuracy of the SQM. The field of view of the SQM is 20°. It cannot be used near the horizon since below the horizon is darker than the sky and this would bias the results.

The output of the SQM is in magnitudes per square arc second. This is an astronomical stellar brightness scale. Zero magnitude per square arc second is the equivalent brightness of the star Vega spread out over a square arc second of sky. One magnitude per square arc second is 2.5 times less bright. It is a negative logarithmic scale. This scale is not familiar to most people besides astronomers but is the standard dark sky survey unit. The error is similar to the repeatability, of about +/- 0.05.

Initially, over 40 locations were used covering the whole AONB from North to South and East to West. On a few nights of identical conditions in one month, an extended red sensitivity digital camera was used with a fisheye lens, on a tripod mounted on the top of the car, to produce all sky images from the few locations that have clear views to the horizon. This could only be done at times of no traffic. The integrations take one minute each. These were later analysed by taking brightness photometry slices from East horizon through the Zenith to West horizon and also South through the Zenith to the North, and plotted out. They were then scaled with the Zenith sky brightness readings from the SQM taken at the same time.

In later months, Zenith photometry was only taken at the locations where all sky imaging had been previously done. On some occasions, the survey was not completed due to change in the weather during the driving between locations. On one occasion meter readings were taken at 45° tilt angles to the Zenith North, South, East and West, for comparison with all sky photometry.

All sky imaging was also taken on some occasions at the end of location runs, from the Mathon observatory, which has a clear horizon in most directions, and is at one of the darkest areas. It was also used as a reference, having a complete log of readings for all observing occasions since 2008. At times of meteor events, this was extended to a series of one minute all sky exposures for up to 90 minutes afterwards.

The SQM data was entered on spreadsheet, with location and reading. A second spreadsheet was used to record for the all sky photometry and associated SQM data for the locations with good horizon.

The all sky photometry locations, with good horizons were as follows:-
Malvern Link common (ML), Poolbrook common (PB), Castlemorton common (CM), Wellington Heath Wye Valley view (WW), Jubilee drive (JD), Ham Green (HG), Alfrick Pound (AP), and Ferney Cottage Mathon (FM).

The additional locations initially studied included Bromesberrow (BB), Hollybush (HB), West Malvern Road (WM), Petty France (PF), Chances pitch (CP), Coddington Lane (CL), Rayners Lane(RL), Colwall (CS), Storridge (SC), and a number of others.

c. A.1, Location Zenith photometry data analysis.

All results were taken vertically at roadside locations and the whole set of data taken within three hours of each other in the time taken to drive from the first location for the last. The aim was to use about the darkest period of the night close to midnight when there was no traffic on the road. Readings were repeated until they were consistent within the error of the SQM. For consistency these were done all on the same night. All were taken from about 10:32 to 01:00 the next morning close to the darkest part of the night. All the locations used had at least a hedge height horizon in one direction, if not more. Care was taken to avoid any obstruction of direct line of sight of the Zenith. On some occasions, some 45° off Zenith points of the compass datasets were also recorded.

d. A.2, Location Zenith photometry results.

The SQM dark sky readings in fig. A1 in Appendix D are presented as a colour-coded grid of 1 km squares covering the whole Malvern Hills AONB. The readings show in the grid, were all taken within three hours of each other by driving from one location to another.

A comparison can be made on a similar scale to the CPRE tranquillity map, and locations identified on the official Malvern Hills AONB geographic map. Those where measurements were made are indicated with the previously described letter code, and the Zenith brightness is in magnitudes per square arc second. The use of the magnitude scale is in common with most dark sky surveys. Other locations not measured are assumed to have in-between values to those adjacent that have been measured. This of course is an inference, but is reasonable. If the visibility changed significantly during that period of data gathering, the data gathering was discontinued.

The general background level overhead doesn't change greatly from one location to another except when close to the main towns. A few kilometres beyond within the Malvern Hills

AONB , the levels are much the same within the repeatability error, on any one night of readings.

The data for subsequent months for selected locations can be shown similarly, but for simplicity has just been used on the temporal variation plots. The geographic variations between them are consistent.

There was some noticeable local variation within 100m on some roads in the darker areas. In every case noted, this was due to overhanging trees or local groups of trees or local rising ground in some critical direction, causing obscuration of parts of the sky at a distance and so reducing the atmospheric scattering.

Jubilee Drive has only one location that has a horizontal view, and that only in one direction to the West . Even with its higher altitude than other sites and obstruction on one side by the Malvern Hills, it did not have any significant darker sky to the Zenith than other rural locations. And even the view to the West towards Wales, had a similar sky brightness to those from Mathon at its lower level, on a subsequent night. So local temporal effects are significant.

A simple comparison was made with the results of photometry of the Exmoor Park Dark Sky survey that gained the Park International Dark Sky status. The readings there were darker than here by at least one magnitude. But the location is far more remote with only open sea to the North, so missing half a hemisphere from ground illumination. Taking the local darkest readings from here, and then removing the effect of half the sky of distant towns , and compensating for distant cities, the results are reasonably consistent with the Exmoor values. The North Norfolk dark sky survey also makes a useful comparison.

e. B, Month-to-month sky brightness variation for selected locations.

f. **B.1 Temporal trend photometry data analysis**

The results of a variation of sky brightness on the darkest nights from month to month are shown in figure B1 in Appendix E. These are taken from subsequent month data from selected locations as described in section d above.

g. B.2 Temporal trend photometry results

The temporal plots show a general trend towards darker values on successive months to December. In Mathon, the darkest nights occur from January to March with the Milky Way no longer overhead, where magnitude 21.1 per square arc second is reached, this has been so over the last three years. It is critically dependent on atmospheric transparency.

The darkest hours are when the rain has washed out much of the dust while humidity is still above dew point and before another weather front moves in. This occurred in 2013 during January and also February during beginning of the dark of the moon period, in the early hours of the morning between conditions of lesser transparency and cloudy periods. This data value has been added to the Mathon dataset; this is 25% (0.3 magnitudes) darker sky than is shown on the grid. It was not practical to do measurements over the whole area at these times, with any reliability, due to such short period temporal variation.

On one occasion there was 100% saturation at 0° C and below, with variable mist on all locations, and those results showed a reduction in light pollution. This accounts for the general kink in the datasets. The likely cause is from atmospheric scattering in all directions including upwards , reducing the horizontal component from the sources.

Atmospheric transparency can vary significantly over of few minutes. Telescopic images of star fields show significant variation in background and transparency from one minute to the next, and also in resolution from atmospheric turbulence. The turbulence changes atmospheric conditions 1000 times a second from one line of sight column of air to the next over a few centimetres width, and is very dependent on the very local thermal air currents and particularly high altitude turbulence in the jet stream and its location. It shows itself as stellar twinkling.

There are occasions when the sky brightness is at a low level and yet the visibility of stars is actually poor. This is due to humidity being close to the dew point with local mist reducing visibility and also horizontal light pollution scattering at the same time. Particularly in the winter periods at 0°C when ice crystals can form in the air locally.

h. C, All sky images and photometry.

i. C.1, All sky images equipment and data gathering .

The image set shown in Fig C1 in Appendix F is a view from the Wyche cutting across the Severn Valley, over Malvern towards Worcester and Bromsgrove. It shows many luminaires shining light above the horizontal, in the viewing direction. In the case of the housing estates close to the hill, this is from many degrees above the horizontal. This is wasted energy, as the lights are not fully directed to the ground. It is this horizontal illumination that has maximum scattering through the atmosphere in the direction of travel, and can be seen over distances to the horizon. The glow in the image is partially from forward scattering between the source and the camera. This causes sky glow in Herefordshire silhouetting the hills over a great distance.

The rest of the images Figs. C1 to C11 were taken with the all sky camera from selected locations with good views to the horizon. These are shown accompanied with East through the Zenith to West photometry plots, as well as from South Zenith to North, and were calibrated against the overhead SQM readings.

The images were done with an all sky camera fisheye lens mounted horizontal on a tripod on the top of a car aligned with the North at the top of the frame in each case. Many of the rural roads have high hedges will overcome by trees, which were avoided. Exposures were one minute at ISO 800. Using a Canon20Da camera and Sigma 8 mm focal length F/3.5 fisheye lens. This digital camera has a modified extended red cut-off filter, normally used to image celestial objects that include deep red emission. SQM readings on this occasion were additionally taken from 45° North South East and West of the zenith, and these were consistent with those from the all sky photometry.

The angular scale is degrees from zenith to horizon. The all sky images were mostly taken over just a few nights of near identical conditions, and only done on one dark of the moon period. Readings required no traffic or car lights to be present for the duration of the exposures.

For the purpose of the photometric Zenith Angle plots, the digital photometric image data, once calibrated at the zenith with the SQM, was converted to millicandelas per square metre. That is a background illumination of one lux from one steradian of sky; there being 2 pi steradians in a hemisphere. A flat horizontal surface will only see pi steradians due to spherical to flat projection affects. This unit is more familiar to lighting engineers although albeit at a level of 1/10000 of street level brightness . Full moonlight is about 300 millilux.

The South to North plots are truncated by the limited field of view of the detector in its 4/5 full 35mm rectangular format. While the East and West plots completely cover from one horizon to the opposite. A full format camera would be required to produce horizon to horizon lots in both East West and North South directions simultaneously.

The fisheye lens was calibrated for vignetting by comparing a daylight image pointing to Zenith with one taken immediately afterwards pointing to the East in late afternoon sky. Pixel signal ratios at 90° angles from each other for the same part of the sky were used to determine the relative sensitivities and a typical cosine^4 scaling curve applied. It amounted to 100% biasing to the horizon respect of the Zenith. This has been applied to the photometry curves, but not the original images.

j. C.2, All sky images and photometry results

The brightest sky glow readings of all the sets were from Malvern Link common. Care was taken to avoid any direct light from street lights, the location being in the darkest roadside part of the common. The next brightest readings were from Poolbrook Common; there, Malvern is mostly to the North, with open countryside to the South. The reduction is consistent with half the sky having less light than previously. The Zenith brightness at these locations is some 30% higher than in the darker locations.

The location data shows a gradual darkening away from areas of large numbers of streetlights. From magnitude 20.2 at Malvern Link common which is surrounded at a distance by built-up area street lit roads; to 20.6 at Poolbrook common, and Malvern town illuminates the sky to the North but not to the South; then onto Castlemorton common several kilometres to the South where the dominant sky brightness as in all cases is to the East.

All the all sky images show a similar trend of a large increase in sky brightness towards the East, and much less so to the West. One may think that this is due to light pollution from Malvern, but this does not entirely account for it. Castlemorton common has the largest clear horizon of all locations. There, Malvern is to the North and North-East. Indeed, this rise to the North can be seen in the data. At Alfrick Pound, Malvern is to the South, while Worcester is still North-East.

Besides the effect of Malvern and Worcester, the increase in sky glow to the East in general is due to the combined light pollution from all the built-up illuminated areas over the Severn Valley and beyond. The rise from Zenith to the East to within 10° of the horizon is approximately 600%. The overall sky brightness at the Zenith is determined by very distant towns, including the cities of Bristol and Birmingham. This sets the Zenith background level for the whole area.

The very high increase towards the East horizon is due to forward scattering from aerosols, that is water droplets and dust in the atmosphere which have very highly directional scattering properties. It is the accumulation of all the light just above the horizontal over huge distances that results in this unnecessary and wasteful sky glow.

In all cases, the effect of the Milky Way can be seen overhead at about midnight. It is present in the images and also on the photometry, as a slight rise towards the Zenith. This is about 15% (0.2 magnitude per square arc second); it will not be present from spring to summer.

Jubilee Drive is obscured by the Malvern Hills entirely to the East and yet the overhead brightness is just the same as elsewhere well away from towns.

In the direction of Wales to the West, sky glow is limited to specific locations such as Hereford. The general background near the horizon is partially backscatter of light and from the illumination sources on the Eastern horizon.

Individual areas on the horizon are due to specific towns at a distance.

It must be emphasised that all the Malvern Hills AONB SQM readings were taken a great distance from any street lights at the point that none could be seen directly at any distance. There are some in the villages, for example two estates at different locations in Cradley that have undirected streetlights, and these can be identified as causing sky glow near the horizon in their directions. Similarly there are commercial units, farm and outbuildings, and private dwellings bordering or in rural areas that have bright outside spotlights. Many are ineffectively pointing near horizontal, which also caused noticeable sky glow at specific directions to the horizon. These are easily seen on slightly misty nights, from some locations.

The overall increase in brightness to the horizon is in line with sky glow modelling from the published photometry of different types of luminaires; references 1 to 5.

The effect of luminaires was modelled with different angle cut-offs, with ground scattering and direct elimination to the air, and scattering downwards in the sky view direction for all angles and distances . A reduction of at least 10 times in sky glow of the same level of light on the ground can be achieved by well aimed lighting that only illuminates the ground with a cut off angles no higher than 60° from vertically down.

k. References

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I. Glossary of terms.

Ambient light: The general overall level of lighting in an area.

Baffle: An opaque or translucent element to shield a light source from direct view.

Beam spread: The angle between the two directions in the plane in which the intensity is equal to a given percentage (usually 10 percent) of the maximum beam intensity.

Brightness: Strength of the sensation that results from viewing surfaces from which the light comes to the eye.

Bulb or lamp: The source of electric light. To be distinguished from the whole assembly (see luminaire). Lamp often is used to denote the bulb and its housing.

Candela (cd): Unit of luminous intensity. One candela is one lumen per steradian. Formerly called the candle.

Candlepower: Luminous intensity expressed in candelas.

CIE: Commission Internationale de l'Eclairage. The international light commission. Sets most lighting standards.

Color rendering: Effect of a light source on the color appearance of objects in comparison with their color appearance under normal daylighting.

Cosine law: Illuminance on a surface varies as the cosine of the angle of incidence of the light. The inverse square law and the cosine law can be combined.

Cut off angle, of a luminaire: The angle, measured up from the nadir (i.e. straight down), between the vertical axis and the first line of sight at which the bare source (the bulb or lamp) is not visible.

Cutoff fixture: A fixture that provides a cutoff (shielding) of the emitted light.

CPRE: Campaign for the Protection of Rural England.

Dark adaptation: The process by which the eye becomes adapted to a luminance less than about 0.03 candela per square meter (0.01 footlambert).

Disability glare: Glare resulting in reduced visual performance and visibility. It is often accompanied by discomfort.

Discomfort glare: Glare that produces discomfort, but does not necessarily diminish visual performance.

Efficacy: The ability of a lighting system to produce the desired result.

Efficiency: A measure of the effective or useful output of a system compared to the input of the system.

Electromagnetic (EM) spectrum: The distribution of energy emitted by a radiant source, arranged in order of wavelength or frequency. Includes gamma-ray, X-ray, ultraviolet, visual, infrared, and radio regions.

Energy (radiant energy): Unit is erg, or joule, or kWh.

FCO, Full-cutoff fixture: A fixture that allows no emission above a horizontal plane through the fixture.

Fixture: The assembly that holds the lamp in a lighting system. It includes the elements designed to give light output control, such as a reflector (mirror) or refractor (lens), the ballast, housing, and the attachment parts.

Floodlight: A fixture designed to "flood" a well defined area with light.

Flux (radiant flux): Unit is erg/sec or watts.

Glare: Intense and blinding light. Never helps visibility.

HID lamp: In a discharge lamp, the emitted energy (light) is produced by the passage of an electric current through a gas. High-intensity discharge (HID) includes mercury, metal halide, and high pressure sodium lamps. Other discharge lamps are LPS and fluorescent. Some such lamps have internal coatings to convert some of the ultraviolet energy emitted by the gas discharge into visual output.

High-Pressure Sodium (HPS) lamp: HID lamp where radiation is produced from sodium vapor at relatively high partial pressures (100 torr). HPS is essentially a "point source".

Illuminance: Density of luminous flux incident on a surface. Unit is footcandle or lux.

Illuminating Engineering Society of North America (IES or IESNA): The professional society of lighting engineers, including those from manufacturing companies, and others professionally involved in lighting.

Incandescent lamp: Light is produced by a filament heated to a high temperature by electric current.

Infrared radiation: EM radiation just to the long wavelength side of the visual.

Intensity: The degree or amount of energy or light.

ILP: Institute of Lighting Professionals

International Dark-Sky Association (IDA, Inc.): A non-profit organization whose goals are to build awareness of the value of dark skies, and of the need for quality lighting.

Inverse-square law: Illuminance at a point varies directly with the intensity, I, of a point source and inversely as the square of the distance, d, to the source. E = I / d2

kWh: Kilowatt-hour: A unit of energy equal to the work done by one kilowatt (1000 watts) of power acting for one hour.

Light pollution: Any adverse effect of manmade light. Often used to denote urban sky glow.

Light trespass: Light falling where it is not wanted or needed. Spill light. Obtrusive light.

Low-Pressure Sodium (LPS) lamp: A discharge lamp where the light is produced by radiation from sodium vapor at a relatively low partial pressure (about 0.001 torr). LPS is a "tube source". It is monochromatic light.

Lumen: Unit of luminous flux; the flux emitted within a unit solid angle by a point source with a uniform luminous intensity of one candela. One footcandle is one lumen per square foot. One lux is one lumen per square meter.

Lumen depreciation factor: Light loss of a luminaire with time due to the lamp decreasing in efficiency, dirt accumulation, and any other factors that lower the effective output with time.

Luminaire: The complete lighting unit, including the lamp, the fixture, and other parts.

Luminance: At a point and in a given direction, the luminous intensity in the given direction produced by an element of the surface surrounding the point divided by the area of the projection of the element on a plane perpendicular to the given direction. Units: candelas per unit area.

Lux: One lumen per square meter. Unit of illuminance.

Magnitude per square arc second: One Magnitude per square arc second is the equivalent brightness of the star Vega spread out over a square arc second of sky. One magnitude per square arc second is 2.5 times less bright. It is a negative logarithmic scale. This scale is not familiar to most people besides astronomers but is the standard dark sky survey unit

Mercury lamp: An HID lamp where the light is produced by radiation from mercury vapor.

Metal-halide lamp: An HID lamp where the light is produced by radiation from metal-halide vapors.

Mounting height: The height of the fixture or lamp above the ground.

Nanometer (nm): 10-9 meter. Often used as the unit for wavelength in the EM spectrum.

PFI: Private Finance Initiative

Photometry: The quantitative measurement of light level and distribution.

Reflector: Controlling light output by means of reflection (mirror).

Refractor: Controlling light output by means of refraction (lens).

Semi-cut off fixture: A fixture that provides some cut off, but less than a full-cut off fixture. Eg. shallow bowls.

SON : high-pressure sodium luminaire, see HPS

SOX: low-pressure sodium discharge tube luminaire, monochromatic sodium light emission, see HID

Spotlight: A fixture designed to light only a small, well-defined area.

SQM: Sky Quality Meter

Urban sky glow: The brightening of the night sky due to manmade lighting.

Veiling luminance: A luminance produced by bright sources in the field-of-view superimposed on the image in the eye reducing contrast and hence visibility.

Vignetting: The falloff of sensitivity of a camera from the centre to the edge of the field of view. This is due to projection of the aperture to the tilt angle from the centre to the edge of a field of view and also mechanical lens obstructions, and also the geometry of the pixel wells. It always follows a cosine to the fourth power law as a function from the centre to the edge of the field of view.

Visibility: Being perceived by the eye. Seeing effectively. The goal of night lighting.

D. Location Data

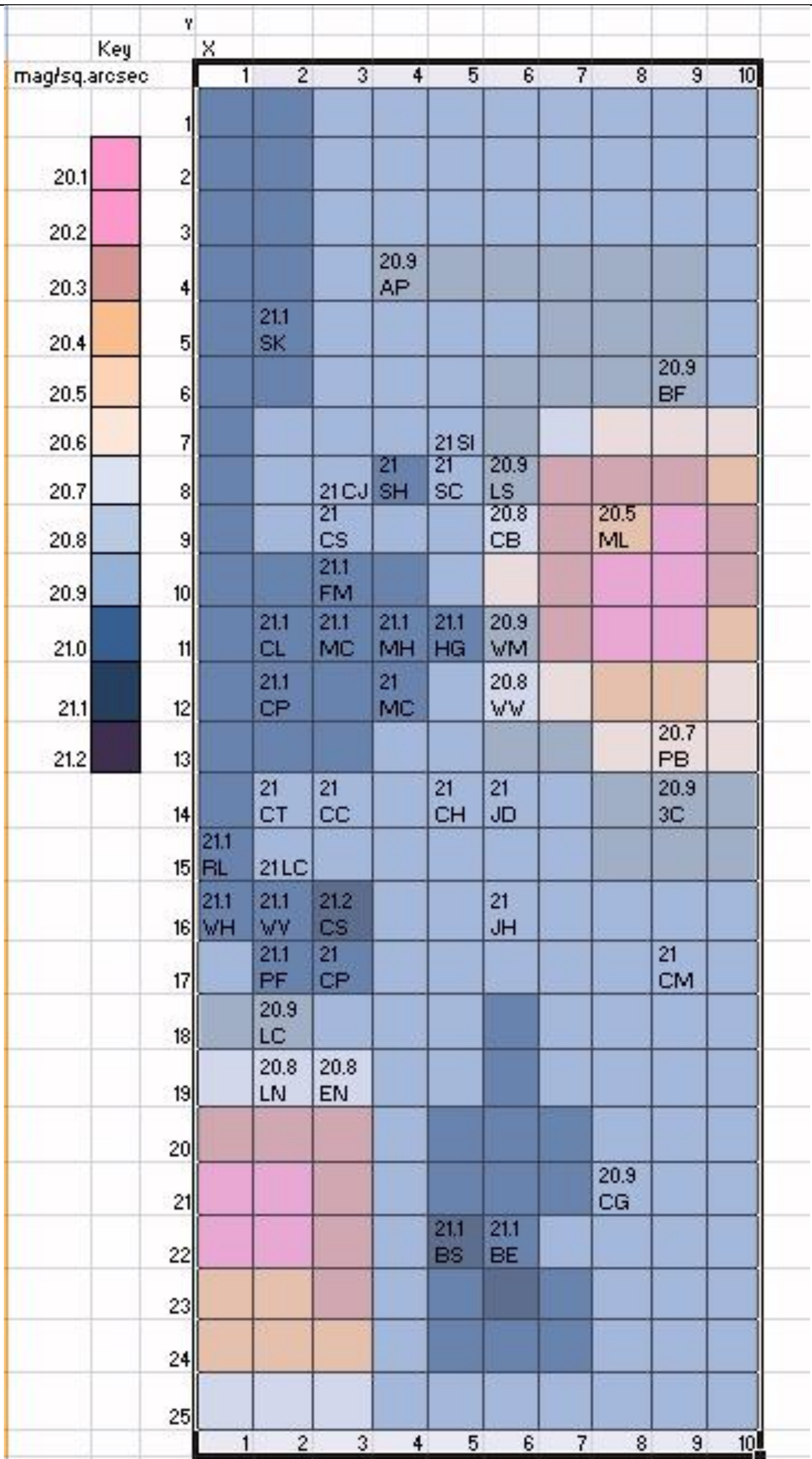
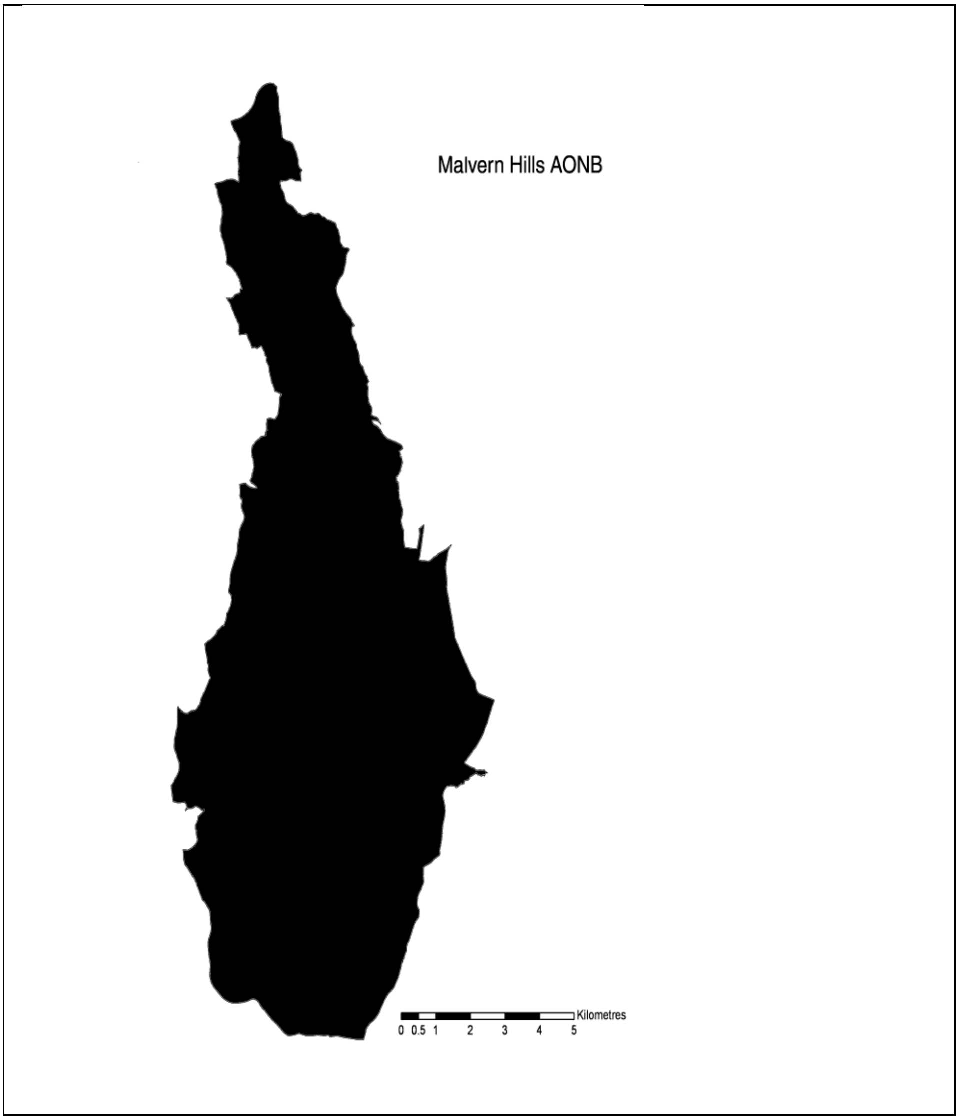
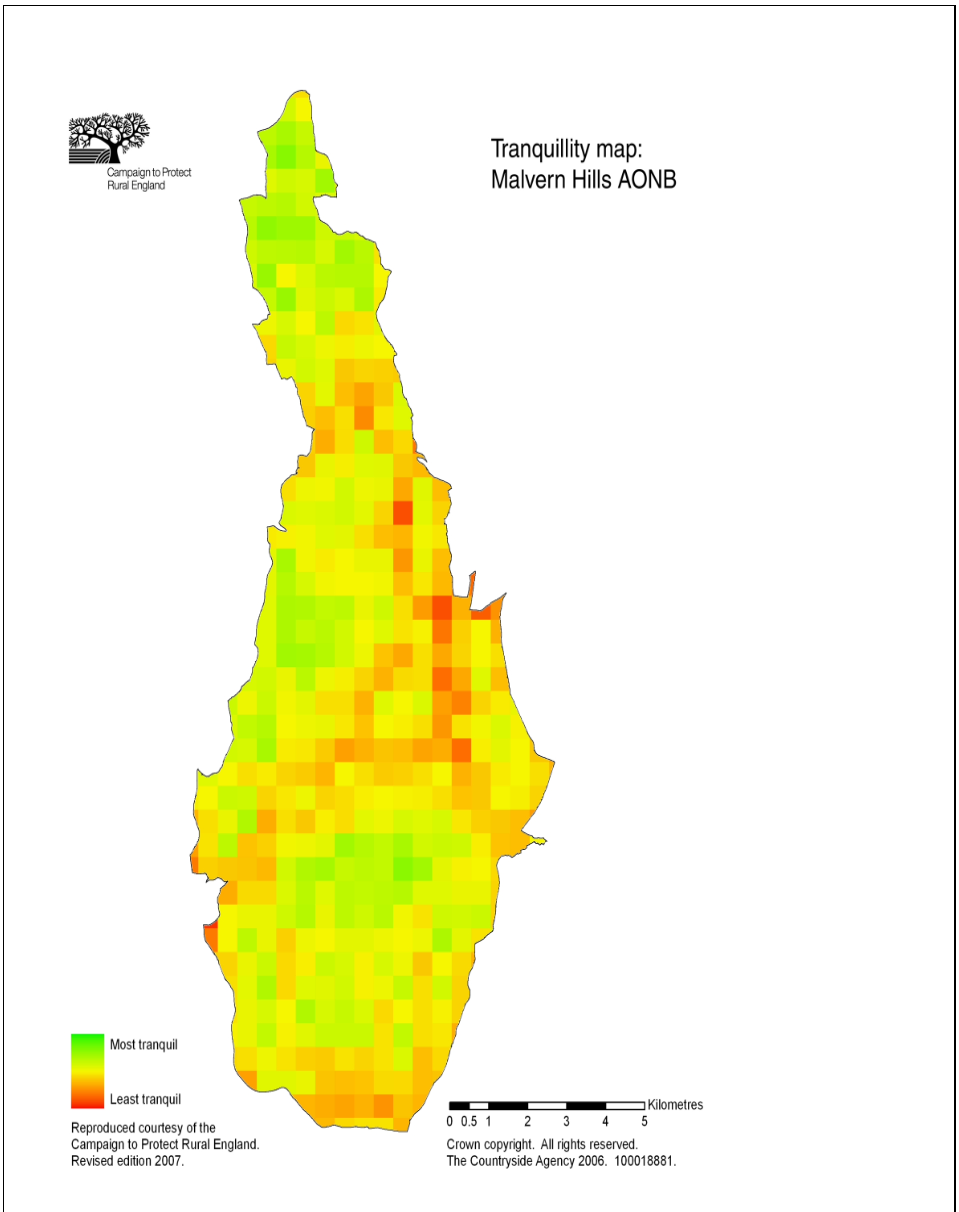
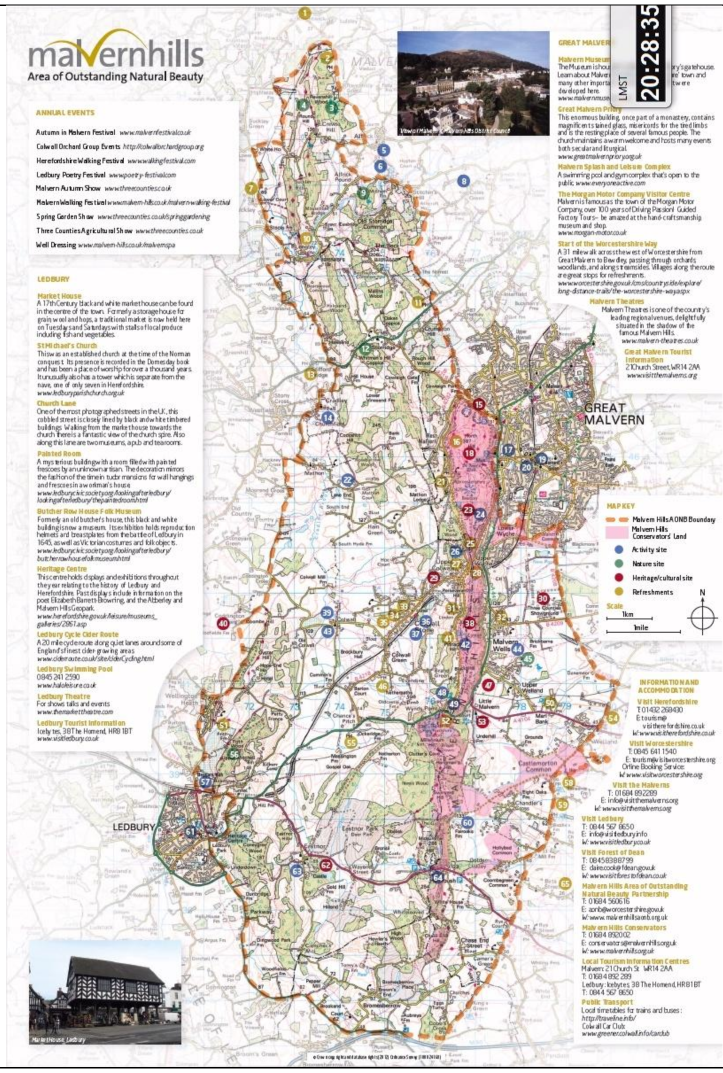


Fig A1. Geographic Location zenith photometry data on AONB 1 km grid.


Malvern Hills AONB
Kilometres
0 0.5 1 2 3 4 5



AONB outline


malvernhills
Area of Outstanding Natural Beauty
GREAT MALVERN
LEDBURY
20:28:35
LMST

AONB map

E. Temporal variation of selected locations from one month to the next.

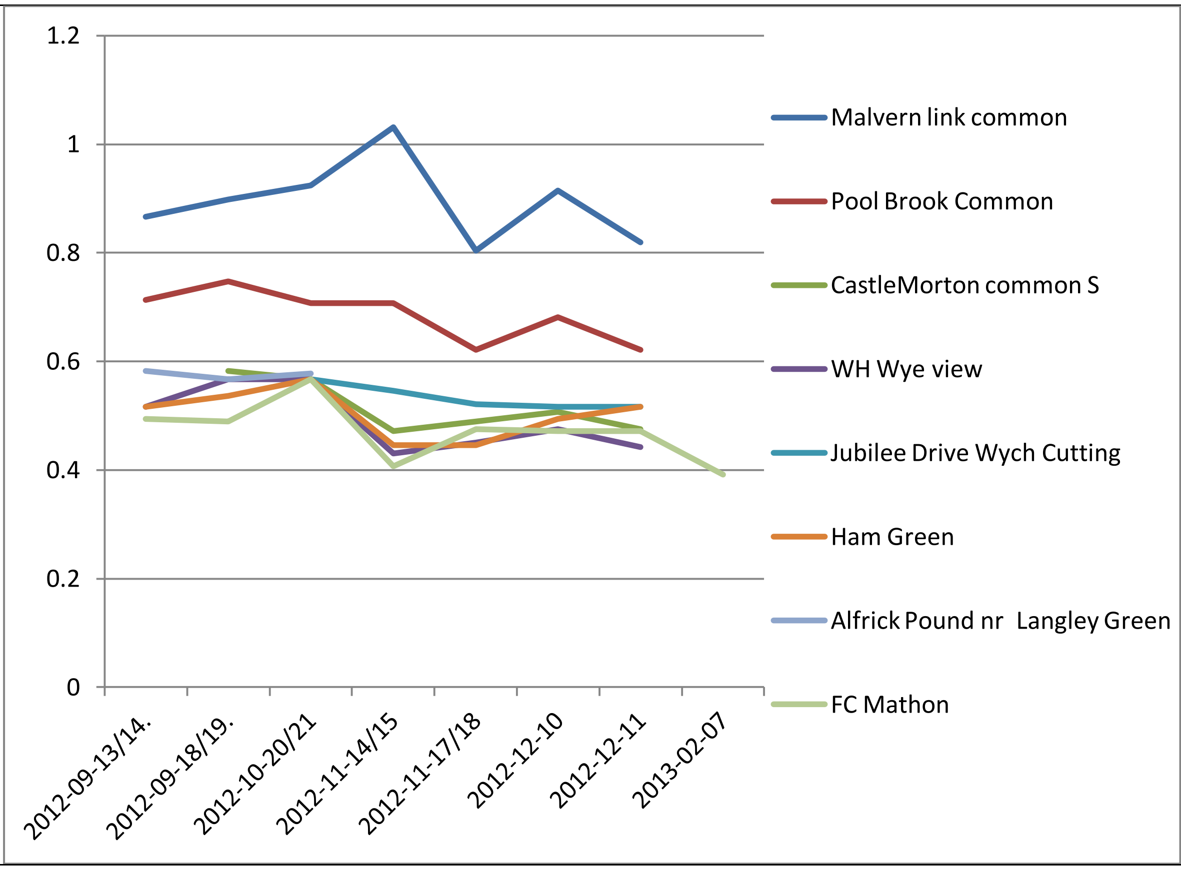


Fig B 1 Plot of Zenith brightness milliCandelas /sq.metre as a function of date and time

F. Images and all sky horizon to Zenith to horizon photometry plots

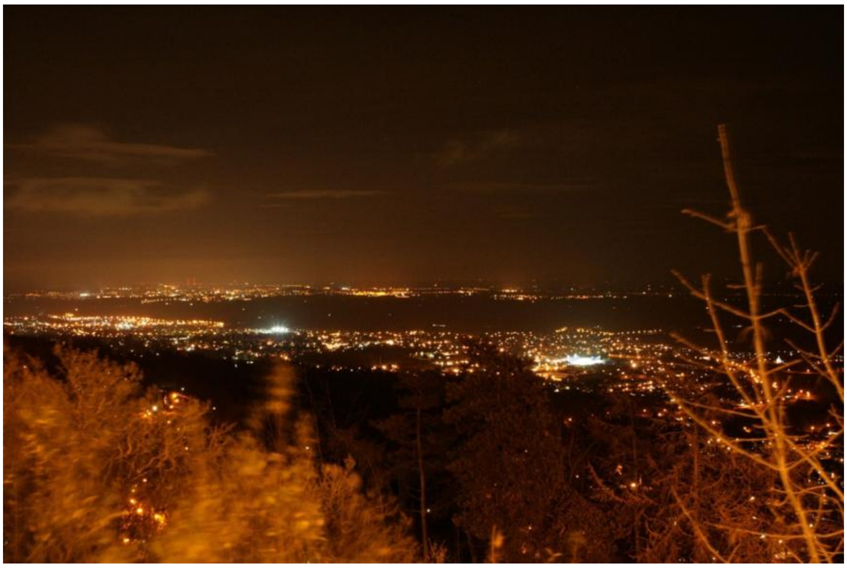


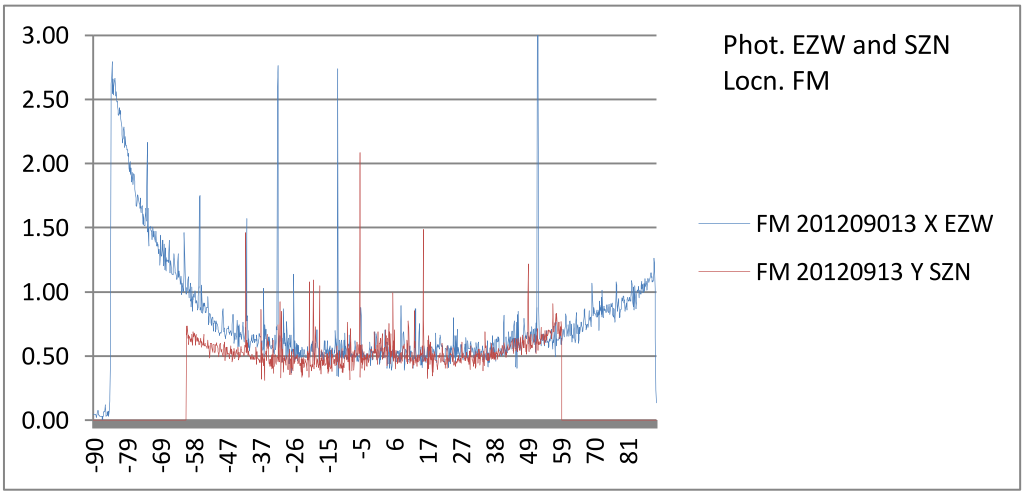
Fig.C 1 View towards Worcester from The Wyche cutting
Showing all lighting above horizontal.

All sky images and East-Zenith-West and South-Zenith-North profile plots centred mid frame, corrected for vignetting.
Photometry Units mill Candelas per square metre for degrees from Zenith .
Spikes are individual stars. Dates shown in the legends.

Zenith

Fig.C 2 Ferney Cottage Mathon 20.72 milli cd/m2

0.56



Zenith

20.70	mag/sq arcsec
0.57	milli cd/m2

Fig. C3 Jubilee Drive

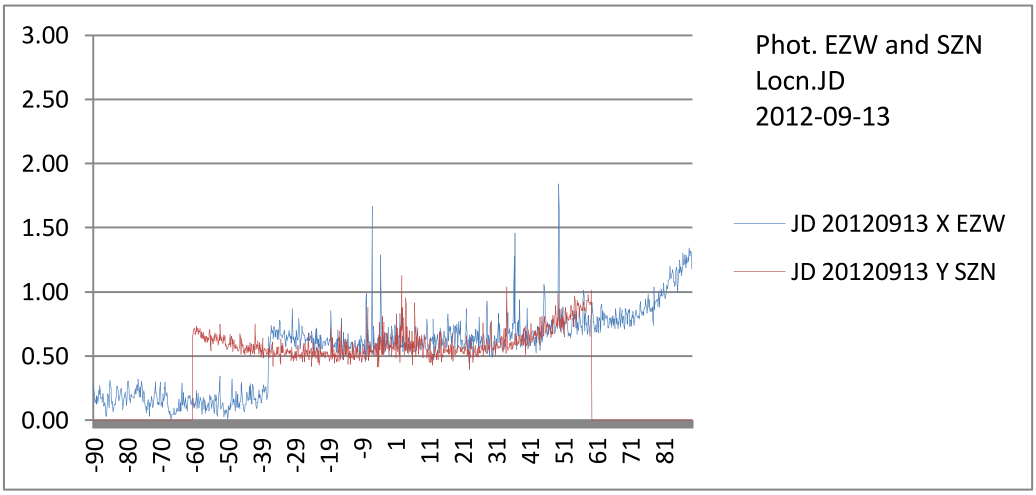


Fig. C 4 Ferney Cottage Mathon

20.70 mag/sq arcsec
0.57 milli cd/m2

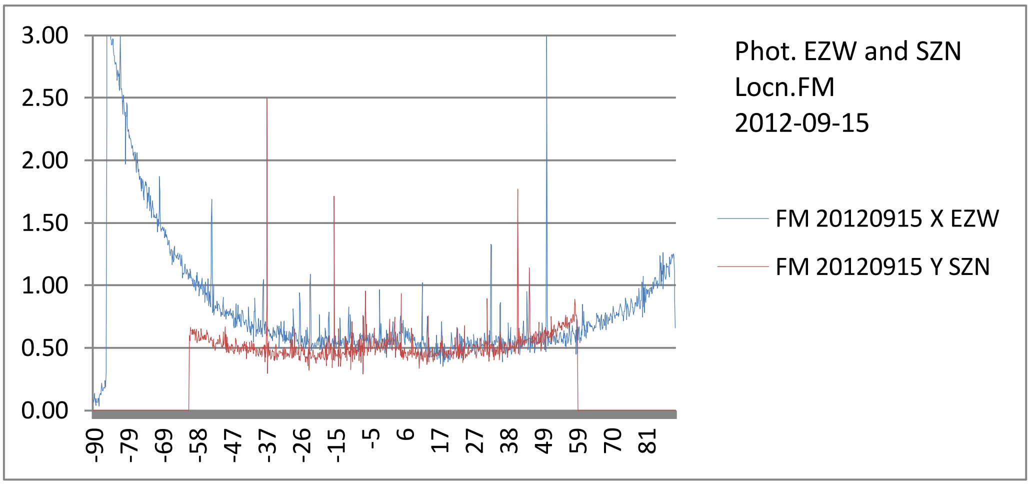


Fig.C 5 Malvern Link Common 20.20 mag/sq arcsec
0.90 milli cd/m2

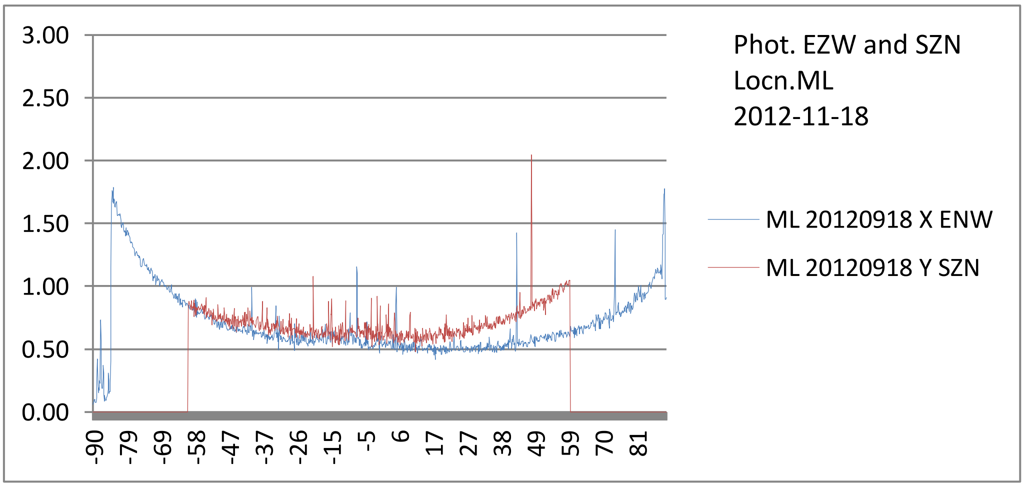


Fig.C 6 Poolbrook Common

20.40 mag/sq arcsec
0.75 milli cd/m2

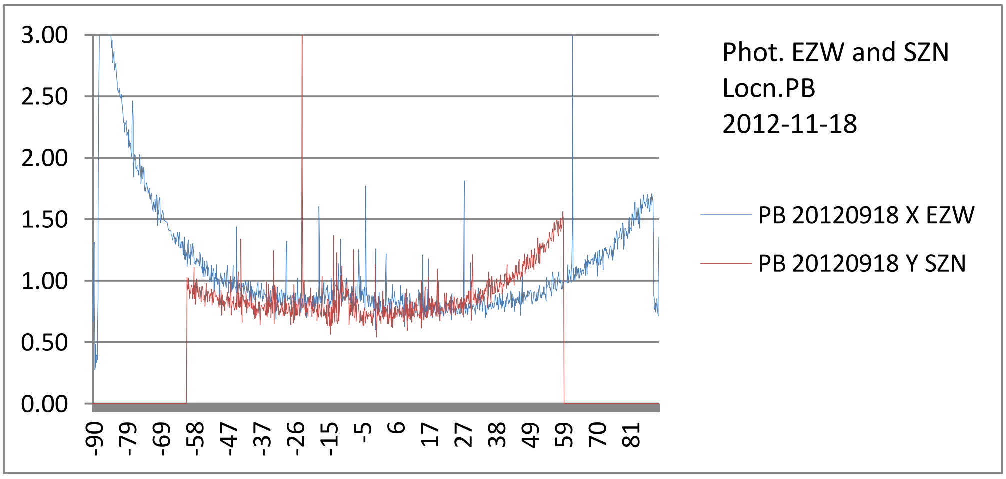


Fig.C 7 Castle Morton Common

20.67 mag/sq arcsec
0.58 milli cd/m2

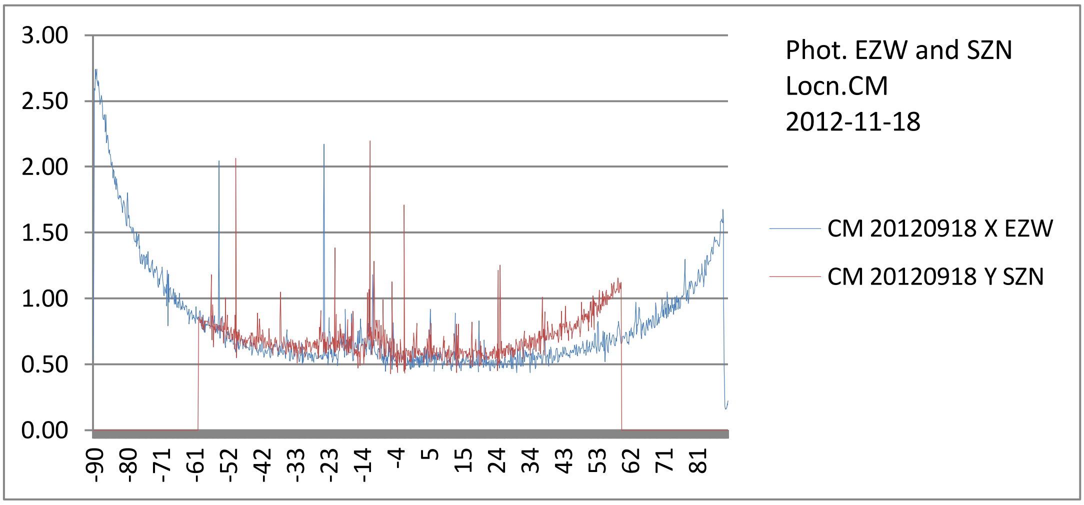


Fig. C 8 Wellington Heath

20.70 mag/sq arcsec

0.57 milli cd/m2

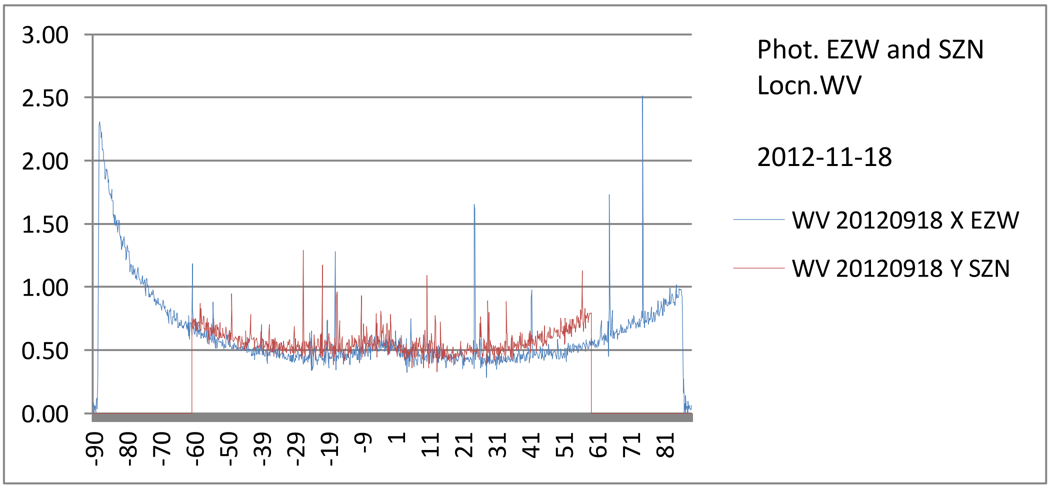


Fig. C 9 Alfrick Pound

20.70 mag/sq arcsec
0.57 milli cd/m2

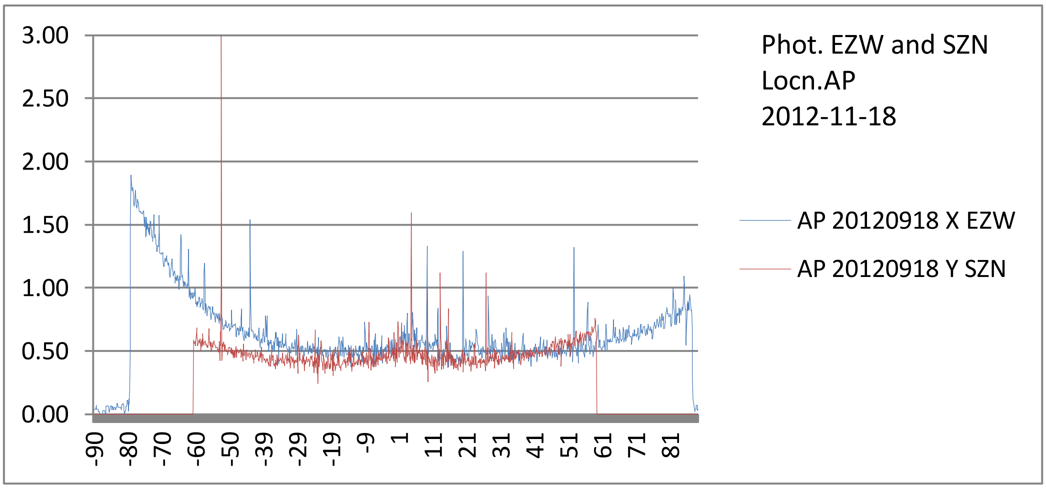


Fig.C 10 Ham Green 20.76 mag/sq arcsec
0.54 milli cd/m2

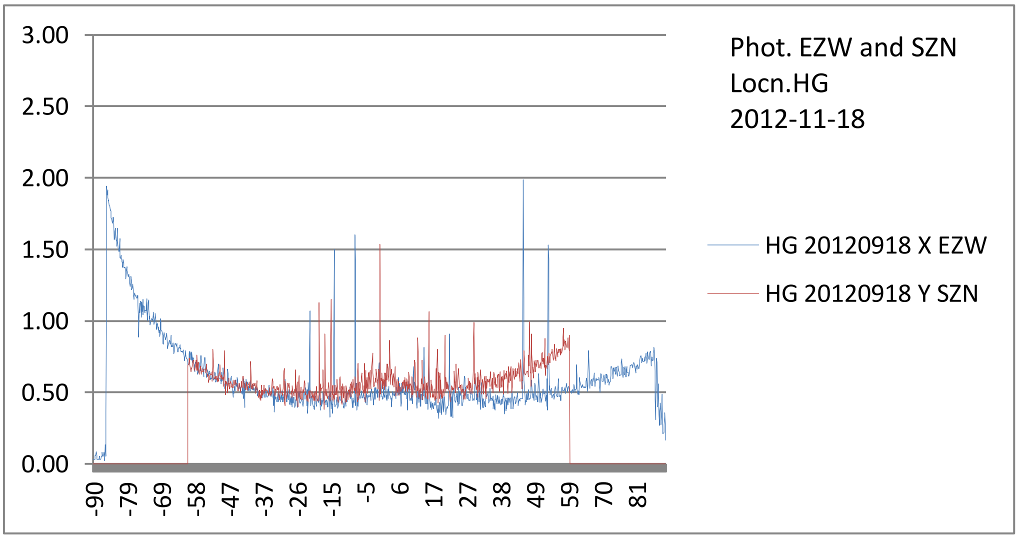


Fig.C 11 Ferney Cottage Mathon 20.86 mag/sq arcsec

0.49 milli cd/m2

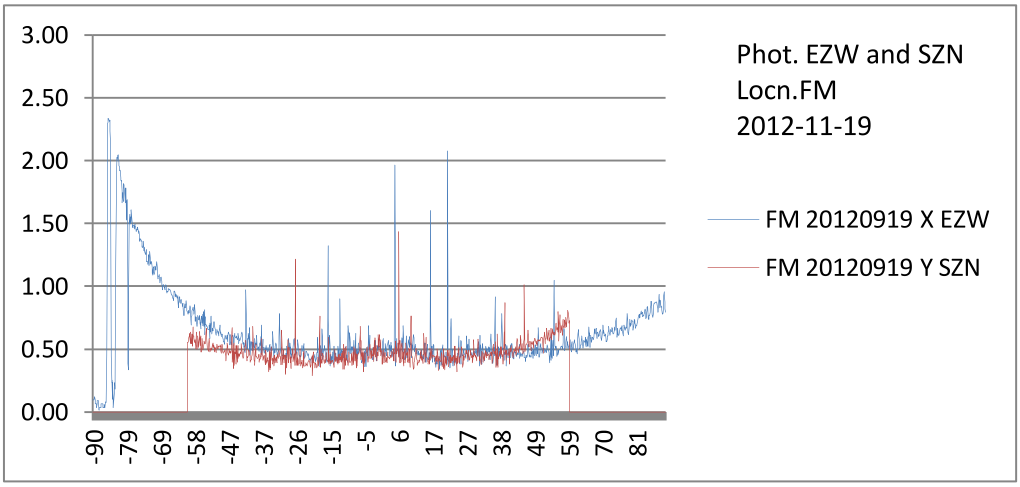


Fig.C 12 Ferney Cottage Mathon 20121118a   20.90 mag/sq arcsec
0.47 milli cd/m2

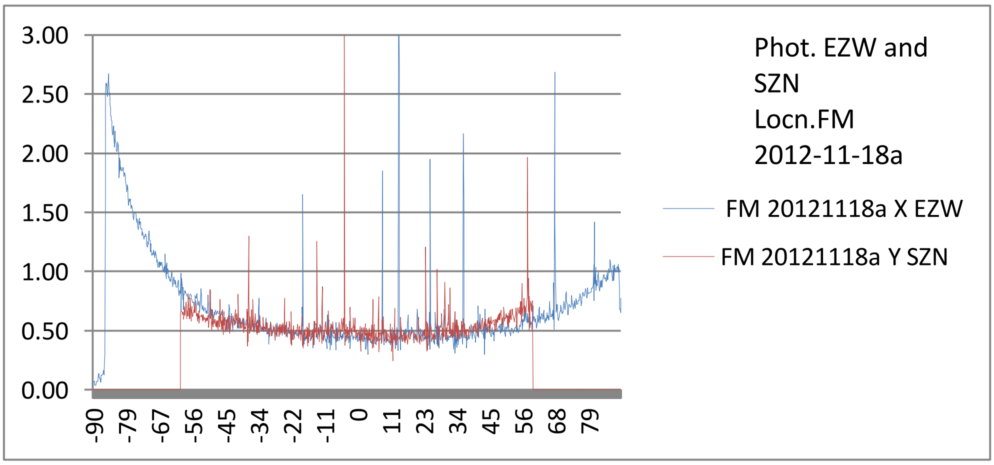


Fig. C 13 Ferney Cottage Mathon 20121118b

20.93 mag/sq arcsec
0.46 milli cd/m2

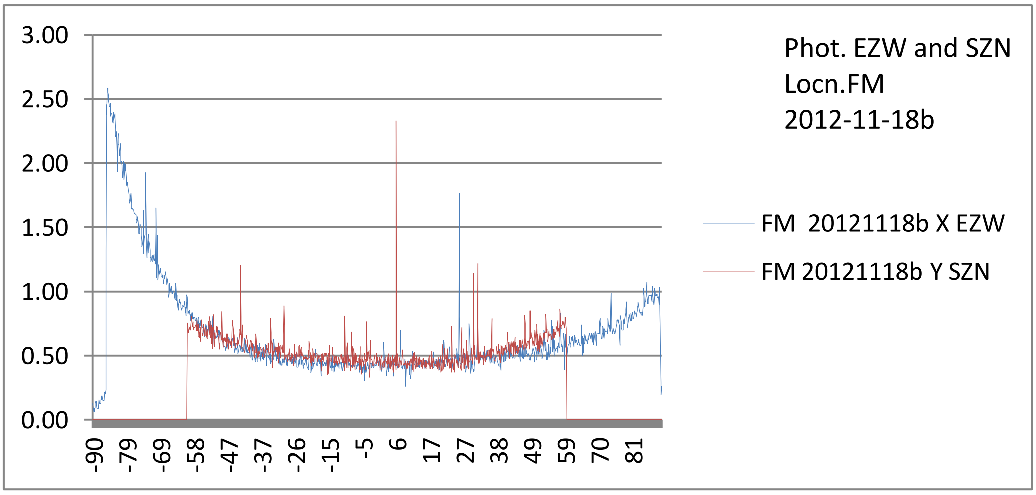


Fig.C 14 Ferney Cottage Mathon 20121118c

20.93 mag/sq arcsec
0.46 milli cd/m2