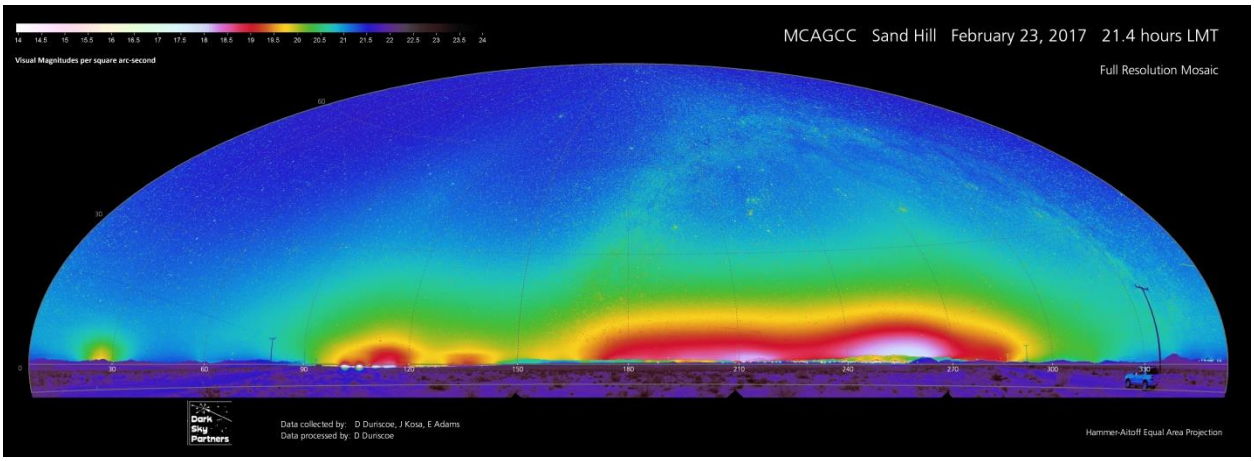
NIGHT SKY BRIGHTNESS AT THE MARINE CORPS AIR GROUND COMBAT CENTER TWENTYNINE PALMS



FINAL REPORT

Prepared by Dark Sky Partners, LLC

June 2017

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EXECUTIVE SUMMARY

This report presents results of night sky brightness measurements made at the Marine Corps Air Ground Combat Center (MCAGCC) located near Twentynine Palms, CA. These all-sky, calibrated measurements were made on the nights of 23/24 and 24/25 February 2017 and show moderate levels of light pollution at the observation point which causes the night visual environment to appear brighter than a naturally dark location.

The overhead sky remains relatively dark, with a zenith sky brightness about 10% higher than that of the Naval Observatory in Flagstaff Arizona. The sky nearer the horizon shows significant "light domes" from regional cities with the largest due to the Los Angeles metropolitan area. These domes produce significant increases in sky brightness near the horizon, resulting in a brightness ratio of 4:1-5:1 between the brightest and darkest zones around the horizon and a brightness ratio of up to 75:1 along profiles crossing the physical horizon in the direction of these light domes. The illumination levels on the landscape and potential vertical surfaces such as buildings or equipment are 2X – 4X times natural illumination levels in the absence of moonlight.

There is an overall darkening of the sky as the night progresses; this darkening amounted to 11% – 12% between the hours of approximately 9 PM and 1 AM. This same degree of darkening was seen on both nights. There was no significant variation in the overall sky brightness detected between the two nights.

A long term monitoring program of sky brightness would enable an assessment to be made of the changes over time of sky brightness at MCAGCC and the degree to which this increase might impair the mission of the facility.

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I. INTRODUCTION

The Marine Corps Air Ground Combat Center (MCAGCC) is located in the Mojave Desert of California between Joshua Tree National Park and Interstate 40. Formerly a very unpopulated region, the southern boundary of the military reserve now abuts the expanding communities of Yucca Valley and Twentynine Palms, which are experiencing population growth rates between four and five percent per year (U.S. Census Bureau, www.census.gov). The larger communities filling the Coachella Valley (including Palm Springs, Palm Desert, Indio and Coachella) are also experiencing continuing growth, and the urban areas of the eastern Los Angeles basin (including Moreno Valley, Riverside and San Bernardino), even though at 35 miles and greater distance, are causing increasingly significant impacts on night conditions at MCAGCC.

Measurements of upward radiance from the Suomi NPP satellite can be used as a qualitative guide to regional light pollution influences. The observed upward radiance from the region around the MCAGCC facility is shown in Figure 1. Note that massive sources of upward radiance from large metropolitan areas of southern California will significantly affect the sky brightness at MCAGCC, in addition to local sources.

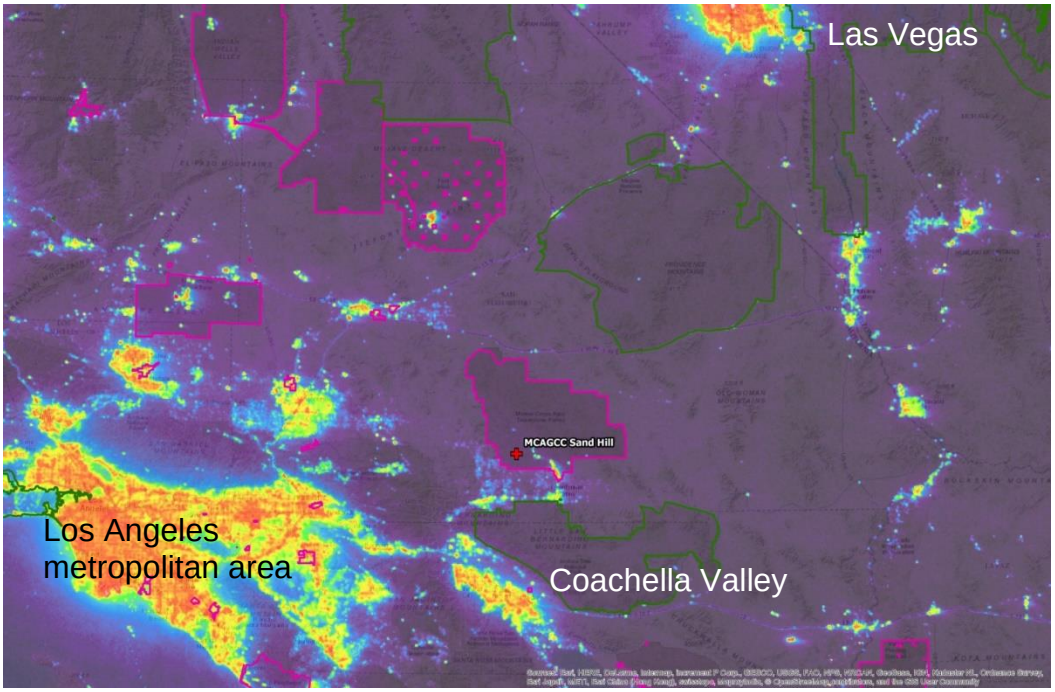


Figure 1. October 2016 satellite image of the upward radiance as seen by the Suomi NPP VIIRS day/night band. The MCAGCC boundary as well as the Sand Hill observation point used in this study are shown, as well as lighting used in the nearby communities to the south, the Coachella Valley farther south, the Los Angeles area to the west, and Las Vegas Nevada at the north edge.

The MCAGCC has requested an assessment of the brightness of the night skies at their facility. MCAGCC conducts many training exercises at night that could be negatively impacted if there is a significant increase in artificial sky glow (light pollution) due to growth in the surrounding region. Dark Sky Partners, LLC (DSP) was contracted to provide measurements of the current

sky brightness conditions at MCAGCC, to serve as a reference against which to assess future trends in sky glow.

II. Study Methodology

The current sky brightness at MCAGCC was measured using a camera system based on the one described by Duriscoe et al. (2007), as employed by the US National Park Service night skies program. These observations are calibrated to the astronomical V (or visual) band measurement system using images of stars obtained in the same data. The V spectral band approximates the response of the light-adapted (daytime or twilight) human eye to light, and includes light of wavelengths between approximately 490 and 650 nm (see Figure 2). The DSP camera system includes significant improvements upon the original NPS system, which allow measurements in multiple wavelength bands at a pace of approximately 7 minutes per sky per band. Only the V-band was used for this study.

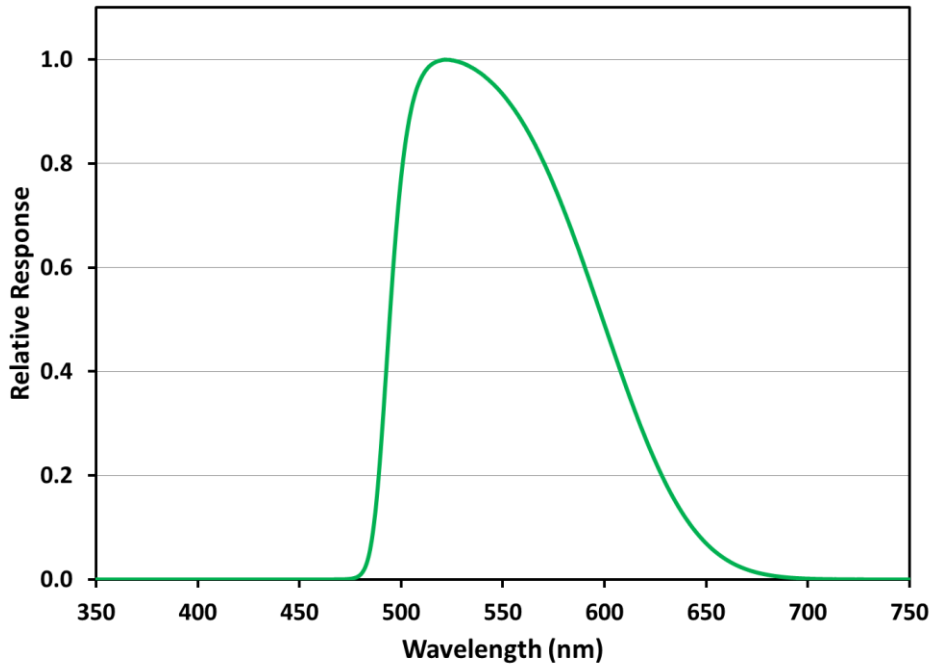


Figure 2. Relative spectral sensitivity for the visual (V) band used for sky brightness measurements in this study.

Complete all-sky measurements in V-band were obtained on two nights at three separate times on each night, to assess the overall sky brightness as well as the variation over the course of a night.

The observations were repeated on two nights in order to assess night-to-night changes. Such changes would be expected to arise from both human-caused and natural variations that would be

detected with more frequent or long-term measures (eg, weekday-weekend variation, holidays, changing atmospheric aerosol amounts, solar activity, etc). Beyond the two nights measured in this study, such monitoring is outside the scope of this study.

III. Sky Brightness Measurements

Sky brightness measurements were made on the nights of 23/24 and 24/25 February 2017 with no moon in the sky. Measurements were made at a location designated by MGAGCC personnel (see Figure 3) located approximately 16 miles from Twentynine Palms and 20 miles from Yucca Valley.

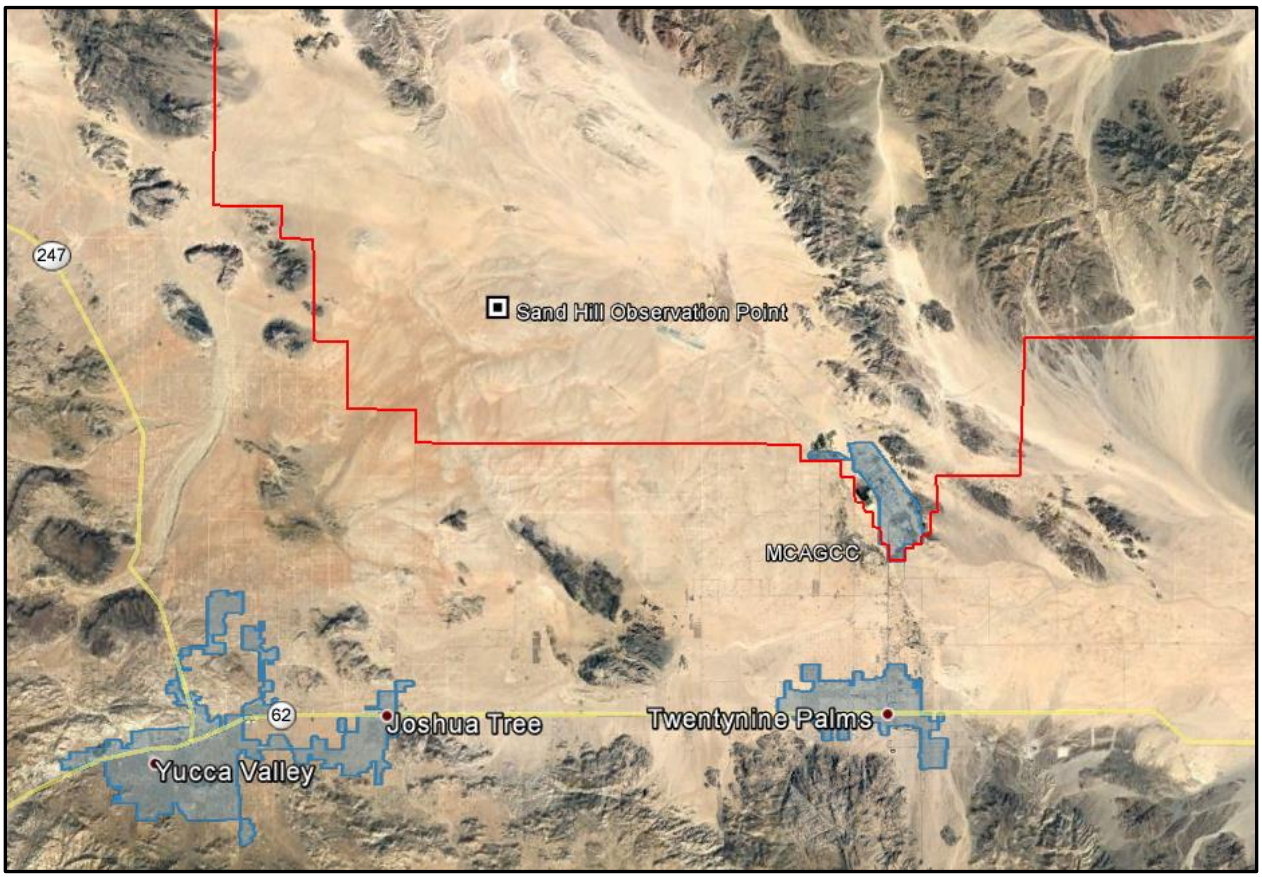


Figure 3. Location of sky brightness observation point on the MCAGCC facility.

Three datasets were obtained on each night starting around 9 PM (PST) and were taken at approximately 2 hour intervals. The sky was clear on both nights with a relative humidity between 43% and 48% at the commencement of observations. The atmospheric extinction, a measure of how much light is scattered in the atmosphere due to particulates, was in the range 0.17-0.19 astronomical magnitudes/airmass (see the Glossary for definitions) on the two nights, typical of skies in the western U.S (see the complete Sky Brightness Measurement Reports in the

Appendix).

Table 1. Summary of the observations.

DATE	START TIMES OF INDIVIDUAL DATASETS (hrs PST)
23/24 FEB 2017	21.1, 23.1, 1.1
24/25 FEB 2017	20.7, 22.6, 0.6

All-sky sky brightness maps are shown in Figure 4 and Figure 5. Hereafter, we refer to these datasets as 24-1 for the first dataset on the night of February 23/24, 24-3 the third dataset on this night, etc. The sky brightness values in these figures are specified in astronomical magnitudes per square arcsecond (mpsas).

There is considerable variation is sky brightness in different areas of the sky due primarily to light from neighboring and distant cities, although there is a significant contribution at azimuths between 100°-110° from the MCAGCC facility. The brightest sky glow at azimuths between 240°-270° arises from the Los Angeles and eastern Los Angeles basin metropolitan areas.

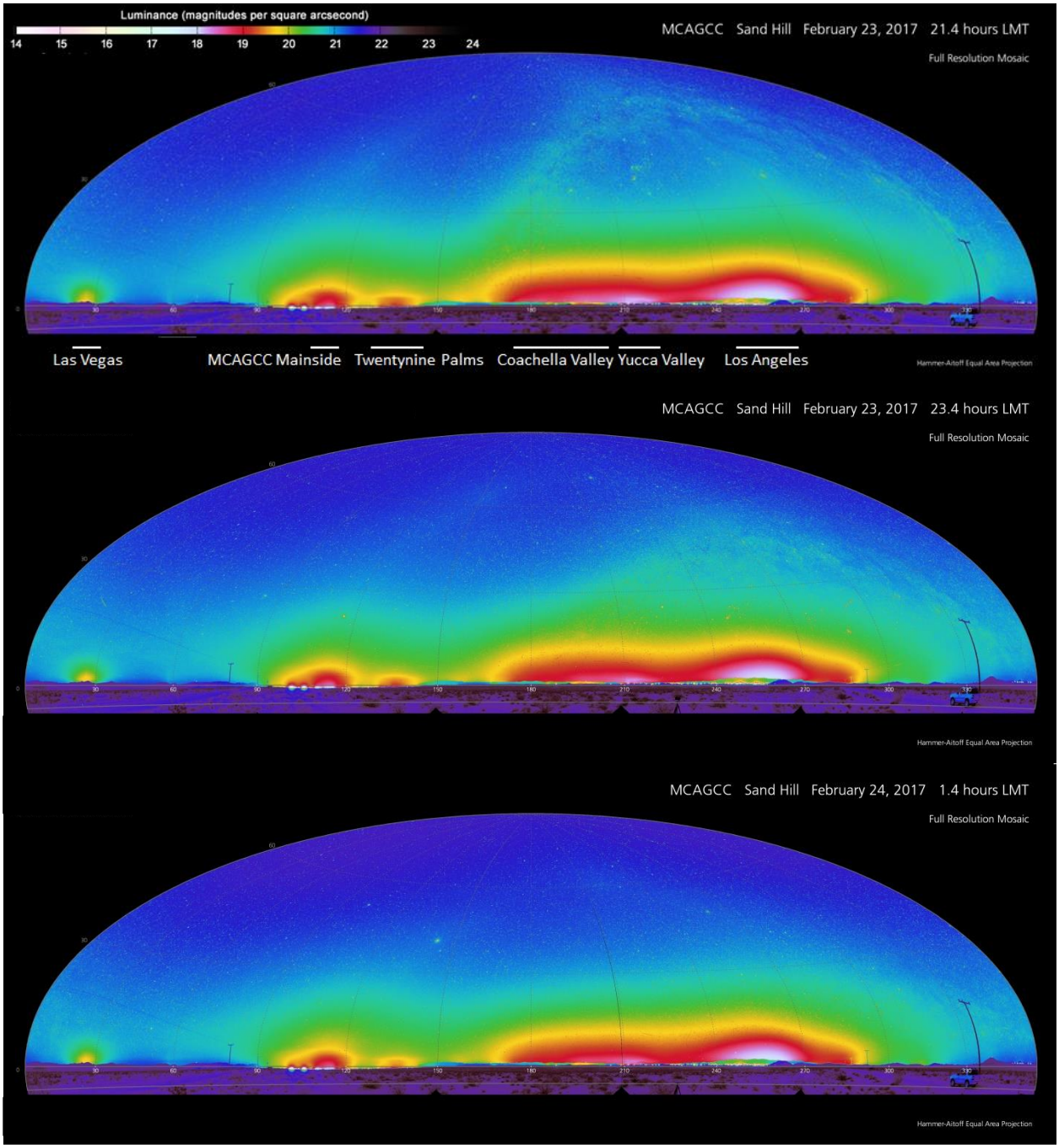


Figure 4. False color all-sky brightness maps showing sky brightness measurements taken at MCAGCC on the night of February 23/24 2017. Prominent sources of the light domes are indicated below the 24-1 (upper) map. The map shows the entire sky hemisphere covering 360° azimuth and from slightly below horizontal to the zenith. The maps are centered at south (azimuth = 180°).

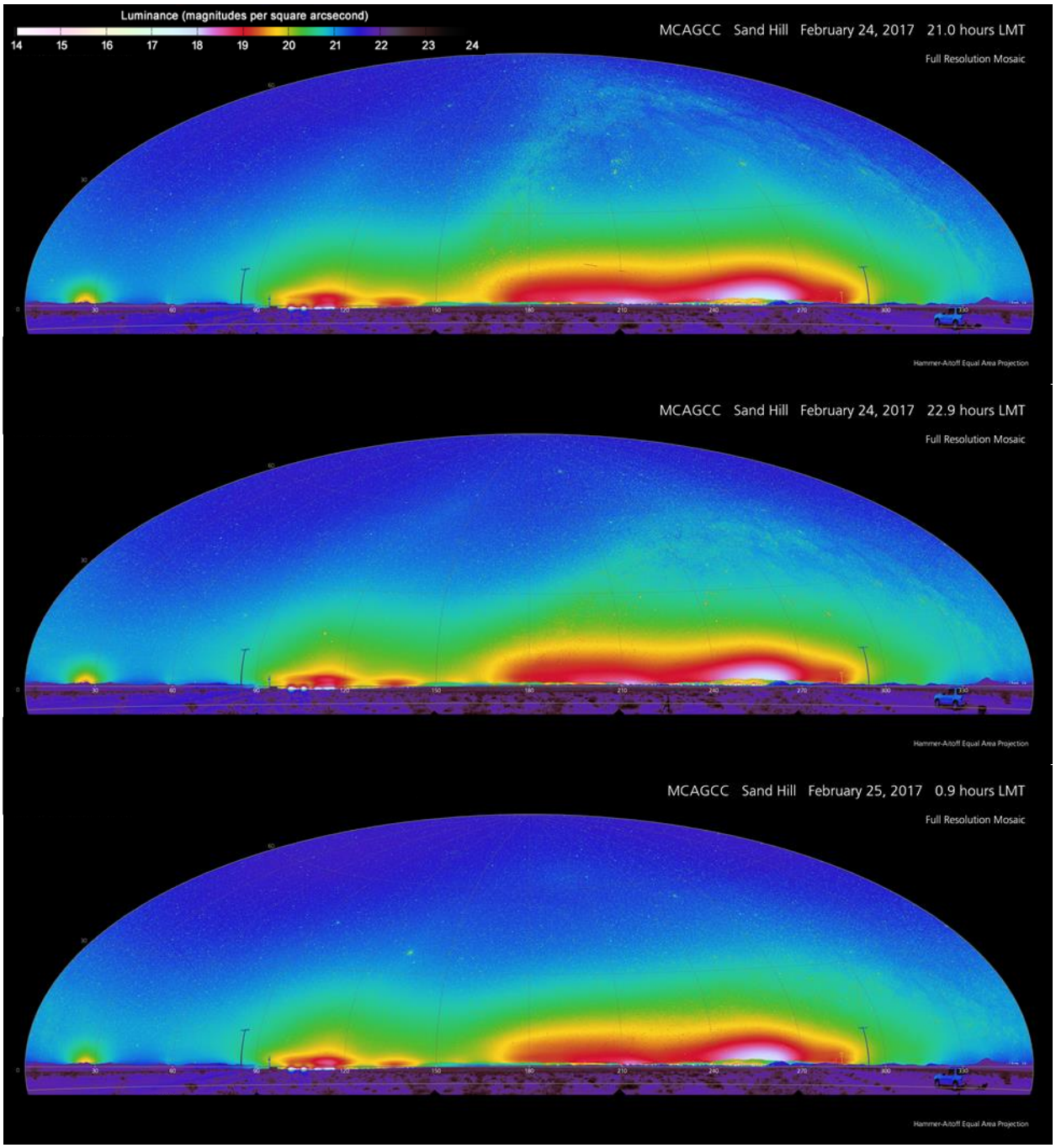


Figure 5. False color all-sky brightness maps showing sky brightness measurements taken at MCAGCC on the night of 24/25 February 2017. The prominent sources visible at the horizon are the same as those identified in the first frame of Figure 4.

IV. Analysis and Discussion

A) Observed Night Sky Brightness

The Average Sky Luminance (ASL, measured in magnitudes per square arcsecond – mpsas) is a measure that characterizes the entire sky and is calculated by averaging the brightness of the sky from the zenith to the physical horizon in the images shown in Figure 4 and Figure 5. Table 2 gives the ASL for the first and last datasets obtained on each night, which shows the full range measured on each night. Also given in this table is the sky brightness at the zenith, a widely used measure of sky quality but one that is relatively insensitive to changes in light pollution levels, particularly in the brighter areas near the horizon.

Table 2. Average sky luminance (ASL) and zenith sky brightness.

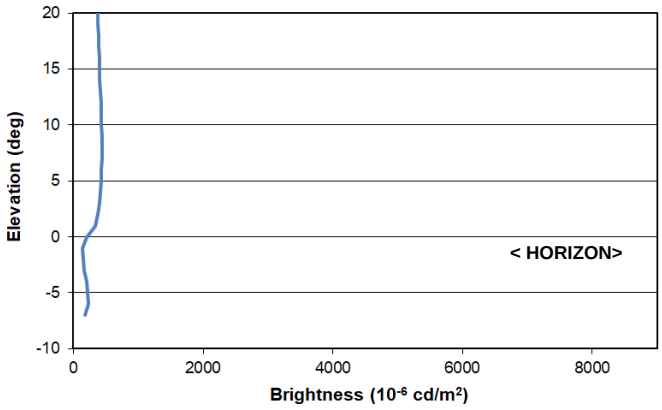
DATASET	ASL (mpsas)	ZENITH SKY BRIGHTNESS (mpsas)
24-1	20.57	21.47
24-3	20.72	21.69
25-1	20.56	21.44
25-3	20.71	21.63

Two points may be made from these data: 1) The overall sky brightness is virtually identical between the two nights for datasets taken at approximately the same time and 2) on both nights, the sky darkens significantly between the first (earliest) and last (latest) datasets. The ASL is 0.15 mpsas fainter and the zenith approximately 0.20 mpsas fainter at 1 PM than at 9 PM. This behavior is typical of sites in which there is significant light pollution and is indicative of reduced anthropogenic lighting over the course of the evening as lighting uses dwindle. There would most likely be a modest further darkening of the sky after 1 AM. These temporal changes are discussed in more detail in Subsection D below.

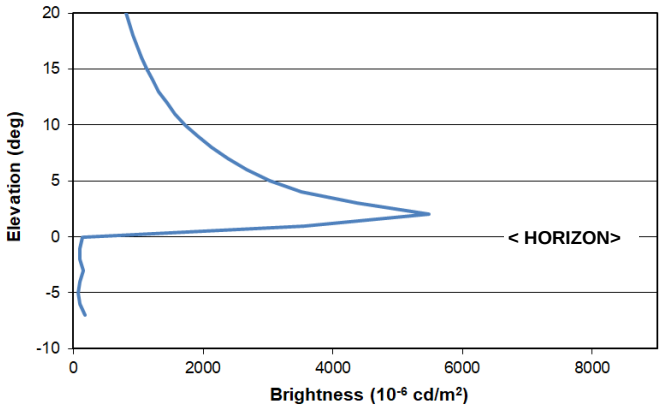
The measured zenith sky brightness at MCAGCC may be compared with that measured at the Naval Observatory in Flagstaff, AZ (pop. 70,320) which was found to be 21.76 mpsas in June 2015. This observatory is located only 5 miles from the center of Flagstaff and has a zenith sky brightness that is about 7%–34% darker than that measured at MCAGCC. Part of this difference may be due to changes in the natural sky brightness between 2015 and 2017.

B) Night Sky Brightness Variation over the Sky

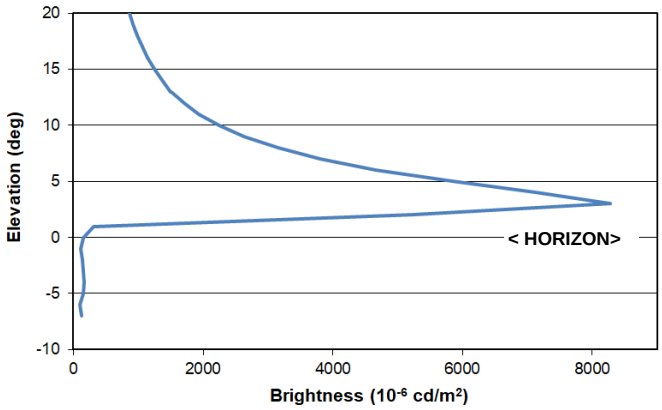
The measures show a considerable variation in sky brightness in different parts of the sky, as seen in Figure 4 and Figure 5. High contrast in a given field-of-view may hinder the ability of persons or instruments to detect or accurately observe people or objects. Sky brightness as a function of elevation angle at three different azimuths for the dataset 24-1 is shown in Figure 6. Note that the measurements include points down to 7° below the physical horizon, and show the contrast between the sky and adjacent horizon that anyone observing in the indicated directions would see. High contrast – or bright sky near the horizon – may hinder detection and observation of objects on the ground.



a) Brightness variation with elevation angle along azimuth = 50°, a nearly unpolluted direction at MCAGCC. The brightness ratio above:below the horizon is ~3:1.



b) Brightness variation with elevation angle along azimuth = 215°. The brightness ratio is ~55:1.



c) Brightness variation with elevation angle along azimuth = 260 °. The brightness ratio is ~75:1.

Figure 6. Brightness variation with elevation angle for three azimuth directions in the 24-1 dataset. Brightness is shown in standard luminance units of 10^{-6} candela per square meter – cd/m^2.

Further analysis was made of the brightest and darkest areas near the horizon by defining specific zones in the sky and determining the average sky brightness in each. A zone was defined by a range of azimuth angles and elevation angles from the horizon to +15°. The brightest zone covers the azimuth range 165°–295° while the darkest zone is between 40°–90° azimuth. The ASL for each of these zones on both nights together with the differences between the brightest and darkest zones are shown in Table 3.

Table 3. Average Sky Luminance (ASL) for the brightest and darkest zones for the first and last dataset on the two nights of measurements together with the ratio between these zones.

NIGHT-DATASET/ZONE	ASL (mpsas)	BRIGHTNESS RATIO
24-1/Bright	19.22	4.85
24-1/Dark	20.93	
24-3/Bright	19.42	3.94
24-3/Dark	20.91	
25-1/Bright	19.22	4.96
25-1/Dark	20.96	
25-3/Bright	19.45	3.85
25-3/Dark	20.91	

C) Illumination of the Ground and Objects

The previous discussion has focused on how bright the sky appears when viewed directly. A related measure is how brightly this light illuminates the ground and objects. Horizontal and maximum vertical illumination levels at the observation point are shown in Table 4. The vertical illuminance is the amount of light falling onto a surface perpendicular to the ground such as a wall or face of a standing person, while the horizontal illuminance measures the light falling onto the ground or other horizontal surface. For comparison, the illuminance with a full moon on a clear night is about 200 millilux. On a clear moonless night in an unpolluted area typical illumination levels are about 0.8 millilux horizontal and 0.5 millilux vertical, so levels at the observation site are approximately 2X – 4X times natural moonless levels.

We note that the values in Table 4 do not include contributions from light sources below the physical horizon, such as were observed from the observation point in the direction of the ordnance bunkers and Mainside. Thus, when facing in this direction the vertical illuminance will be higher than listed in Table 4, as discussed below.

Table 4. Horizontal and vertical illuminance values at MCAGCC – sky sources only.

DATASET	HORIZONTAL ILLUMINANCE (millilux)	VERTICAL ILLUMINANCE MAXIMUM (millilux)
24-1	1.4	1.7
24-3	1.2	1.5
25-1	1.4	1.8
25-3	1.2	1.5

A representative plot of the vertical illuminance at all azimuths is shown in Figure 7 for the first dataset taken on 24 June. This shows that the light dome toward the west dramatically increases the illumination level for a surface facing in that direction (i.e. azimuth about 230°). The directly visible light sources toward MCAGCC Mainside, ordnance bunkers and Homestead Valley (azimuths ~100° – 260°) can be seen here to increase the illuminance at those azimuths by at least[1] 0.2 millilux, or ~12% – 20%.

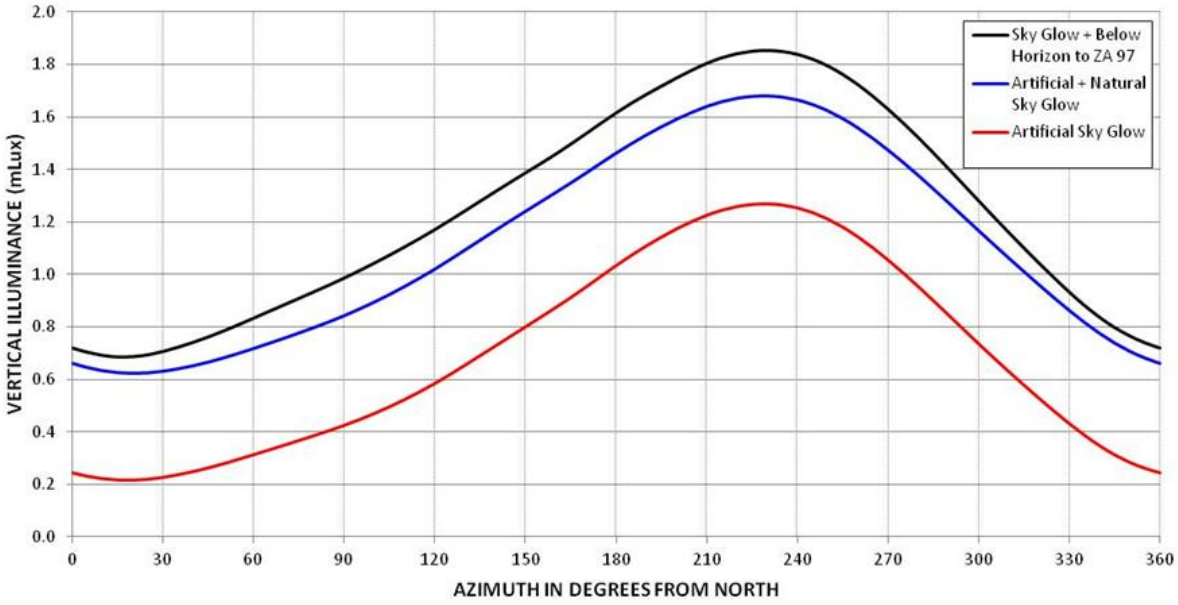


Figure 7. Vertical illuminance in millilux as a function of azimuth for the 24-1 dataset. The red line includes contributions from the artificial sky glow only; the blue line includes both artificial and natural sky glow contributions, while the black line shows all contributions from the sky as well as light sources and light reflected from the landscape at zenith angles up to 97°.

D) Artificial Sky Glow (Light Pollution)

The sky brightness measurements discussed in the previous sections are those arising from the total sky brightness which consists of two components: 1) natural sky brightness and 2) artificial sky glow, or light pollution. It is the latter component that is of most concern due to the long-term increase arising from population growth and the expansion of urban areas and residential development in the region.

To evaluate the artificial or "light pollution" contribution to the total sky brightness, a model of the natural sky brightness (Duriscoe, 2013) was used to determine the natural contribution for each dataset. Subtracting this component from the measured total sky brightness leaves the artificial component only. An example all-sky map of the artificial sky glow for the 24-1 dataset is shown in Figure 8.

[1] The contribution to vertical illuminance from unshielded lights may be up to 0.3 millilux greater than what was measured by the camera because of pixel saturation on these bright sources.

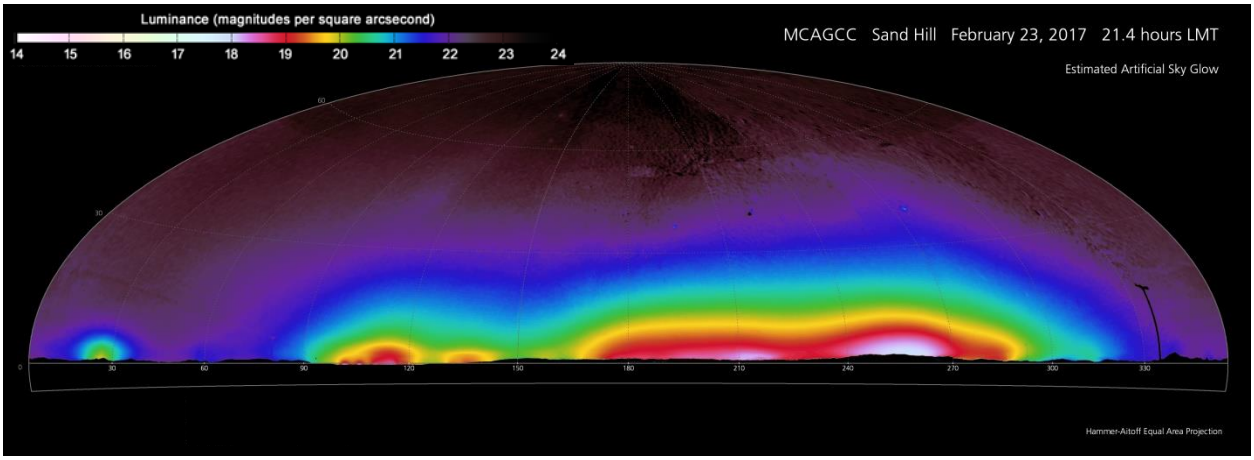


Figure 8. Estimated artificial sky glow map from the first dataset on 23/24 February 2017.

Total observed ASL sky brightness, the artificial and natural components, as well as changes observed from the beginning to the end of each night's observations, are summarized in Table 5. These data show that the natural component is approximately half (43% – 51%) of the total observed sky brightness, and that between 9 PM and 1 AM local time the total ASL decreased by 11% – 12%, due primarily to a 20% – 23% decrease in the artificial component. It is important to recognize that these ASL figures represent average values over the whole sky: the fractional contribution of the artificial component closer to the horizon in the light domes associated with cities is much larger.

Table 5. Total (TOT), artificial (ART) and natural (NAT) ASL components for the four datasets, as well as the proportions of the artificial and natural components of the total, and fractional changes between beginning and end of each night's observations.

DATASET	TOT	CHANGE	ART	FRACTION OF TOTAL	CHANGE	NAT	FRACTION OF TOTAL	FRACT. CHANGE
24-1	20.57	-12%	21.19	0.56	-20%	21.47	0.44	-0.01
24-3	20.71		21.44	0.51		21.49	0.49	
25-1	20.57	-11%	21.19	0.57	-23%	21.48	0.43	+0.05
25-3	20.70		21.47	0.49		21.43	0.51	

E) Direct Visibility of Light Sources (Glare)

There are significant light sources directly visible to observers at ground level at the Sand Hill observation point. The brightest of these are located toward azimuth ~100° – 110° at the Mainside development and at ordnance bunkers (see Figure 9, upper panel). Light sources are also directly visible toward the west, associated with development in Homestead Valley, including the communities of Flamingo Heights, Johnson Valley, Landers, and Yucca Mesa (see Figure 9, lower panel). These lights are significantly brighter than any other naturally occurring light sources visible in the nighttime landscape or sky, and besides producing glare contribute significantly to vertical illuminance of objects viewed in the night landscape as noted in Subsection C above. These sources can be expected to have an effect on visual dark adaptation during nighttime training operations, as well as potentially affecting or interfering with

equipment used to assist night vision.

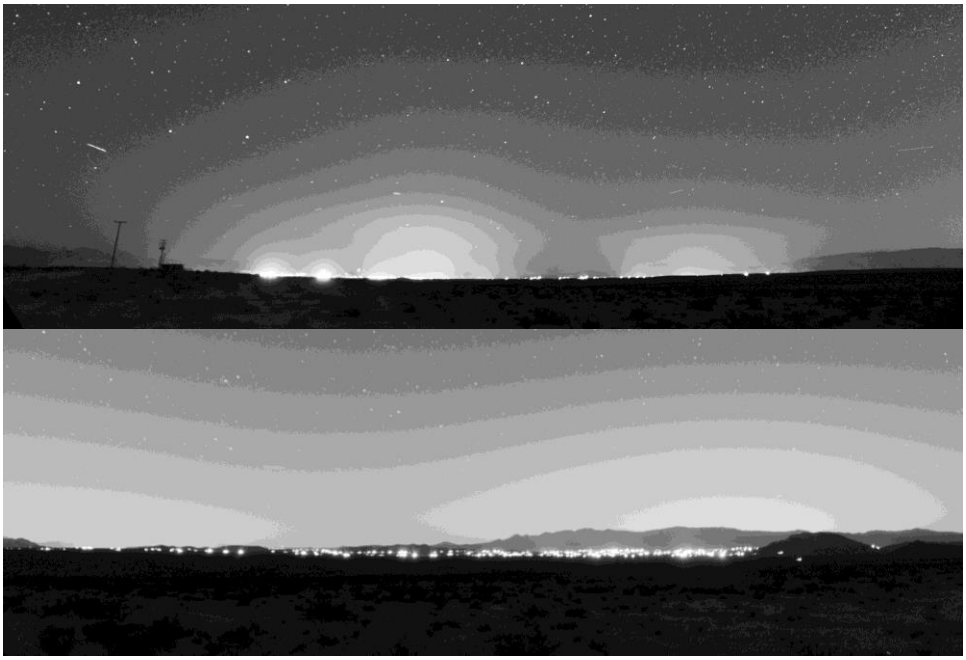


Figure 9. Unshielded light sources directly visible from the Sand Hill observation point in the Mainside and ordnance bunker developments on MCAGCC (upper panel), and toward Homestead Valley (lower panel).

V. SUMMARY

All-sky, photometrically-calibrated measurements of the night sky were made at MCAGCC on two nights in February 2017. These measurements show moderate levels of light pollution, which causes the night visual environment to appear significantly brighter than a naturally dark location, particularly when observing near the horizon and toward the west. Much of the Mojave Desert is now suffering from a similar degradation of what was once a nearly pristine night sky.

In some respects the site remains relatively dark, with a zenith sky brightness about 10% higher than that of the U.S. Naval Observatory in Flagstaff AZ, the Navy's dark-sky astronomical observing site. But there are significantly brighter "light domes" from regional cities with the largest and brightest due to the Los Angeles metropolitan area. These domes produce significant increases in sky brightness near the horizon, resulting in a brightness ratio of 4:1-5:1 between the brightest and darkest zones around the horizon and a brightness ratio of up to 75:1 when viewing just above to just below the horizon. Directly visible light sources particularly at the MCAGCC Mainside and ordnance bunker areas, as well as to the west toward the Homestead Valley, may impact human night vision and training conditions.

There is an overall darkening of the sky as the night progresses; this darkening amounted to 11% – 12% between the hours of approximately 9 PM and 1 AM. This decrease is due to reduced anthropogenic lighting – most likely due primarily to decreased vehicular traffic – over the

course of the evening. The total observed sky brightness, as well as the variation during the night, was nearly identical on the two nights observed.

Though the sky brightness is only moderately increased above natural levels at angles 30° and greater above the horizon, the significantly increased brightness arising from light domes near the horizon increases illuminance of the ground and objects viewed in the landscape about 2X – 4X above what would be observed on a moonless night in an unpolluted area.

Establishment of a long term measurement program at the MCAGCC to monitor night sky conditions and light source visibility should be considered. Results from such a program would then be evaluated against mission requirements to assure that conditions needed to meet the MCAGCC mission are maintained, and if threats to mission capability are demonstrated, to help establish quantitative guidance for mitigation of light pollution impacts. The requirements for such a monitoring program would need to be established in consultation with MCAGCC personnel but, at a minimum, would require assessment of critical mission thresholds and at least annual measurements as undertaken here. Formulation of mitigation strategies should commence in parallel with the monitoring program due to the long lead time needed to implement measures for off-base light sources.

One step that could be implemented now would be to review lighting on the MCAGCC facility. The brightest lights visible when making the observations came from sources on the base itself.

VI. REFERENCES

Duriscoe, D.M. (2013), "Measuring Anthropogenic Sky Glow Using a Natural Sky Brightness Model", Pub. Astron. Soc. Pacific, 125: 1370.

Duriscoe, D.M., Luginbuhl, C.B., and Moore, C.A., (2007), "Measuring Night-Sky Brightness with a Wide-Field CCD Camera," Pub. Astron. Soc. Pacific 119: 192.

VII. GLOSSARY

Candela. Unit of luminous intensity, in a given direction, of a source that emits monochromatic radiation of frequency 540×10^{12} hertz and that has a radiant intensity in that direction of 1683 watts per steradian.

Illuminance. The luminous flux per unit area of the incident surface. Measured in units of lux = 1 lumen/meter^2.

Lumen. The unit of luminous flux, equal to the amount of visible light emitted per second in a solid angle of one steradian from a uniform source of one candela.

Luminance. The amount of light emitted from a surface per unit area. Sky brightness luminances are commonly specified in astronomical magnitudes per square arcsecond (mag./arcsec^2). The lighting profession measures luminance in candela per square meter or nits. 21 mag./arcsec^2 = 450 microcandela (µcd) per square meter.

Magnitude (astronomical). A logarithmic measure where each magnitude corresponds to a change in brightness or radiant energy of a factor of 2.5, and smaller numbers correspond to brighter measures.

Nanometer (nm). One billionth of a meter. Commonly used to specify the wavelength of light emissions.

Lux. Unit used to measure illuminance, or the amount of visible light falling onto a surface. Defined as one lumen per square meter.

APPENDIX

Sky Brightness Measurements Reports

Dark Sky Partners Data Collection Event Report Explanation

February 2017

Introduction

This document provides a quick explanation of reports generated from the database of values extracted from the all sky image mosaics with anlaysis software. A brief description of each table, and each attribute reported within them, is included. For the theoretical basis and methods of computation the reader is referred to a more complete document (Duriscoe 2016).

A "Data Collection Event" is a combination of date, location, and camera representing when and where sky brightness data was collected. Each event has an unique code, comprised of letters and numbers, the letters referring to the location and the numbers to the date YYMMDD. The date is defined at the start of data collection in Universal Time (UT). Hence it s often one day later than Local Time, either Standard, Daylight, or Local Mean Time (LMT), for locations in North America if data collection is begun in the evening. A "Data Set" is one complete set of 45 or 7 images that cover the entire sky. Multiple data sets are often taken over the course of the night to detect changes in artificial sky glow from evening to early morning. Occasionally a new event is designated with the suffix "A" at the same date and location.

The Data collection event report contains three main sections: 1) general attributes of the data night and each data set, 2) a list of populated places that may contribute to sky glow observed, and 3) the sky brightness and estimated artificial sky glow mosaics for each data set, illustrated in false color in panoramic equal-area projection, with a table of derived statistics and indicators of the impact of light pollution. The report provides a “snapshot” of the photic environment at the time of the observations as well as an estimate of the impact from artificial sources.

Photometric units of measure used include *SI* units of luminance (candela per square meter) and illuminance (lux), as well as astronomical units of luminance (magnitudes per square arc second) and illuminance (magnitudes) in the V, or visual, band. *SI* units are linear, astronomical units are inverse logarithmic, that is, smaller values indicate brighter objects, and negative values are possible.

Page 1. Metadata and visual observations

First line: Data Event Code, client name, Location name, and Date (UT)

Data Night Attributes Table

Longitude: Longitude in decimal degrees (west is negative), Datum WGS 84, taken with GPS receiver, typical horizontal positional accuracy 5 meters

Latitude: Latitude in decimal degrees (north is positive), Datum WGS 84, taken with GPS receiver, typical horizontal positional accuracy 5 meters

Elevation (m): Elevation above mean sea level in meters, taken with GPS receiver, typical vertical positional accuracy 15 meters

Camera: Short description of the camera used. The camera name is usually the manufacturer, such as SBIG (Santa Barbara Instruments Group), followed by a number representing the CCD sensor type, (e.g. SBIG 1001E).

# of sets: A count of the number of individual data sets collected over the night at this location.

Exposure (secs): Exposure (or integration) time of each image in seconds.

Air Temp (C): Air temperature at start of image acquisition as measured by a portable weather meter in degrees Celsius. Typical accuracy is 3 degrees.

R.H. (%): Relative humidity at start of image acquisition as measured by a portable weather meter. Typical accuracy is 5%.

Wind Speed (mph): Average wind speed at the start of image acquisition as measured by a portable weather meter held at eye level. Typical accuracy is 3 mph.

ZLM: Zenith limiting magnitude, or the faintest stars than can be observed visually without optical aid (naked eye) near the zenith, or darkest part of the sky. This observation varies somewhat from observer to observer, but all observers are instructed to practice the same methods. 6.6 is considered near pristine under average conditions. 7.0 is achievable under good seeing conditions and with proper dark adaptation of the eye. 7.4 is excellent, just about the faintest attainable, although some observers have confirmed seeing stars as faint as magnitude 8.2 with the naked eye. A number lower than 6.3 usually indicates significantly degraded sky quality.

BORTLE: A semi-quantitative measure of the sky quality observed visually, as developed by astronomer John Bortle. Classes are whole numbers 1-9, with 1 the very best and 9 the poorest.

SQM: A measurement taken with the Unihedron Sky Quality Meter, in magnitudes per square arc-second (mag arcsec^{-2}), aimed at the zenith.

OBS-1, OBS_2, OBS_3: Name(s) of the observer(s).

NARRATIVE: A descriptive narrative of the conditions observed visually during the night of data collection. This usually includes seeing (a measure of atmospheric steadiness), and transparency (a measure of atmospheric clarity) in semi-quantitative terms. Also may include characteristics of the site, the appearance of certain astronomical features, and the suitability of the site for visual astronomy by persons interested in amateur astronomy.

Data Set Attributes Table

Data Set: Data set number

Quality Flags: *Useable*--Y or N (yes or no), a determination as to whether or not the data should be included or rejected based upon inspection of the mosaic; *Collection*--(1-5, 1 poorest, 5 best) a semi-quantitative judgment as to the quality of data collection, including such factors as camera and mount performance, accuracy of mount setup, presence of stray light; *Processing*--(1-5, 1 poorest, 5 best) a

semi-quantitative judgment as to the quality of data processing, including image calibration, atmospheric extinction calculation, instrument zeropoint calculation; *Atmosphere*--(1-5, 1 poorest, 5 best) a semi-quantitative judgment as to the quality of atmospheric conditions, where excellent transparency and steadiness, low relative humidity, and the complete absence of clouds or smoke plumes is best.

Natural Sky Model: A report of the amount of natural *airglow* used at the *zenith* in micro-candela per meter squared (μcd m^{-2}), the *Fit Quality* of the model (1-5, 1 poorest, 5 best), a semi-quantitative judgment as to the quality of natural sky model fit based upon inspection of the artificial sky glow mosaic as compared to the natural sky model mosiac, and *Natural sky model fit notes*, which explain why the operator assigned the zenith airglow intensity and fit quality reported.

Extinction: A report of calculated all-sky atmospheric extinction for each data set. Extinction is a measure of the opacity of the air, the units are astronomical magnitudes per airmass. Airmass depends on its zenith angle and the relationship is not linear. A star viewed at the exact zenith is by definition view through one airmass. This value is computed for each data set from measurements of 50-150 standard stars on the images over the entire sky.
Attributes reported in the table include: *Extinction coefficient* in V magnitudes per airmass, *Standard error of Y*, in V magnitudes, a measure of the fit of the observed data to a regression line (0.035 or smaller is excellent while 0.06 and larger is poor), and the *Number of* reference *Stars used* and *rejected* in the regression equation. Rejected stars are outliers of greater than 0.1 magnitude, presumably because they were partially masked by horizon obstructions or clouds, measured incorrectly because of scintillation, or measured incorrectly because of within-pixel variations in the sensitivity of the CCD detector.

Collection Properties: A report of the observed *percentage of clouds* in the entire sky, the *Average Pointing Error* of the camera mount system in degrees (less than 0.25 is excellent, more than 0.5 is poor), the Maximum Pointing Error of the camera mount system in degrees (less than 0.4 is excellent, more than 1.0 is poor), and the *total bias drift* of the camera over the course of the 45 or 7 images in each data set in raw camera ADUs (more than 10 ADU drift may indicate a camera problem).

Page 2(-3). Populated Places Table

A table of places within 300 km of the observing site is displayed ordered with decreasing potential to produce artificial sky glow. The places name (*Place*) and *Population* are given from the 2010 U.S. Census. The *Distance* in kilometers, apparent *Azimuth* , and *Apparent Half-Width* in degrees as seen from the observer's location are given based upon the longitude and latitude of the place's centroid and assuming a circular area whose diameter is computed based upon the land area of the populated place given in the Census database. Finally, each place is ordered according to *Walker's* Law, a formula which predicts sky glow intensity of a populated place as a function of its population and distance from the observer. The numbers shown in the table for this attribute are a unitless ratio with linear scaling. An arbitrary cutoff is made for the lower limit of this value that includes a reasonable number of populated places (less than 50).

Pages 3(4) +. All-sky Photometry Report

The all-sky photometry report is scaled so that one data set fits on one page, and multiple data sets are reported on succeeding pages.

First Line: The *Data Event* Code, the *Date* in Local Mean Time (LMT), the *Time* of the middle of image collection in LMT in decimal hours, whether or not (Y or N) the data set is the *Reference* set for the night,

and the *Data Set Number*. Local Mean Time is used for comparison between locations and data nights, with local midnight being 0.0 hours. Local midnight is the time when the sun is at its maximum position below the horizon.

First Figure -- Full Resolution Mosaic

The full resolution mosaic of the data set's images rendered in false color. Each individual image is placed in the mosaic after correction for pointing errors, and projected into a Hammer-Aitoff equal area projection with the horizon at the center vertically and a fixed azimuth at the center horizontally. The false color scheme reveals a wide dynamic range of sky brightness values in a logarithmic scale from 14 to 23 mag arcsec^{-2}. The all-sky image mosaic (zenith to 6 degrees below the level horizon) contains about 34 million pixels. Land features and individual light trespass sources are often visible in this rendering.

Photometry of all sources Table

A table of summary measures from the sky brightness mosaic is given. The sky brightness mosaic is derived from the full resolution mosaic by applying a strong median filter to screen out stars, then resampling to 0.05 degrees per pixel resolution, for a total of about 8 million pixels covering the entire sky in an equal-area projection. Bright unshielded lights in the land portion of the mosaic will not be accurately measured for two reasons: they commonly are so bright their recorded luminance exceeds the dynamic range of the detector so they become clipped or saturated at the maximum ADU value, and the median filter will remove most of the light from these sources since they resemble stars or point sources. Therefore "all sources" should not be interpreted to include accurate measures of light tresspass from visible individual lights, even if they appear in the full resolution mosaic. Very bright sources such as this will often cause vertical lines or "column bleeds" in the full resolution image; these are removed by the median filter technique before statistics are calculated. A graphic of the sky brightness mosaic is not shown in the report.

Average Sky Luminance is an important statistic describing the photic environment. It is reported in logarithmic units of mag arcsec^{-2} and linear units µcd m^{-2}. The natural moonless reference condition is set at 21.6 mag arcsec^{-2} or 250 µcd m^{-2}. This is an unbiased measure of the amount of light reaching the observer from sky luminance.

Zenith Luminance is often reported as a sky quality indicator in the astronomical literature. This measure is calculated from the median pixel value of an approximately one degree diameter circle centered on the zenith. 22.0 mag arcsec^{-2} or 172 µcd m^{-2} is generally considered to represent the darkest part of pristine skies, any value lower (brighter) than 21.3 mag arcsec^{-2} usually indicates significantly degraded sky quality, unless the measurement falls in the Milky Way, the natural airglow, or bright portions of the Zodiacal Light.

Brightest Square Degree is an important value because the human eye's ability to dark adapt will be impaired by the brightest part of the visual scene, and because bright parts of the sky may cast shadows from 3D objects on the land surface, giving depth to an otherwise uniformly lit natural landscape. The brightest part of the Milky Way is 19.6 mag arcsec^{-2} or 1500 µcd m^{-2}. Brighter values will begin to impair dark adaptation, values brighter than 18.0 mag arcsec^{-2} can cast shadows.

The *Synthetic SQM* value is given for comparison to a measure with the Unihedron Sky Quality Meter. It is considered to be more accurate than the actual measure, since it is computed from the sky brightness mosaic based upon accurate alignment to zenith and accurately calibrated CCD camera data. The sky

brightness values in the data set are subjected to an algorithm that matches the SQM response curve with zenith angle. The units are mag arcsec^{-2}. Values of 21.3 and greater (darker) fall within the range of "natural" skies (Bortle Class 1-3), 19.5-21.3 may be considered significantly degraded skies (Bortle Class 4-6), while values less than 19.5 may be considered severely degraded (Bortle Class 7-9). The SQM is only sensitive to areas of the sky 30 degrees above the horizon and higher, so will not measure bright sources of artificial sky glow along the horizon.

Total luminous emittance exactly correlates with average sky luminance, but in units of illuminance. It represents the total luminous flux from the sky if all the light were collected into a point or source of small angular diameter, like the moon. This summary value excludes the light from individual stars and planets and glare from unshielded lights but includes the Milky Way, Airglow, Zodiacal Light, and artificial sky glow. When expressed in astronomical magnitudes it can be compared with the moon at various phases (-8 at crescent, -11 at half phase, and -12.5 at full phase). A value larger (darker) than -7.0 is exceptionally dark; between -7.5 and -7.0 is typical for near pristine locations. A value smaller (brighter) than -8.0 usually indicates significantly degraded sky quality.

Horizontal and Maximum Vertical Illuminance are important measures of the amount of light striking the ground (horizontal) or a vertical plane (vertical). The units are milli-lux (mlux). The natural reference condition for moonless nights is 0.8 mlux for horizontal and 0.4 mlux for vertical. The maximum vertical illuminance is for a plane facing the brightest part of the sky near the horizon.

Second Figure -- Estimated Artificial Sky Glow

The sky glow mosaic is the sky brightness mosaic subjected to pixel by pixel subtraction of a registered natural sky model mosaic (the natural sky model is not shown as a graphic in the report) rendered in the same false color scale as the full resolution mosaic. The resolution is 0.05 degrees per pixel. Land features and individual light trespass sources are masked out so that only sky luminance from artificial sky glow is shown. This is an at-a-glance representation of the amount of light pollution from sky glow observed at the site. Artificial sky glow will always be brighter near the horizon than at the zenith and its impact on the natural lightscape substantial.

Photometry of Artificial Sky Glow Table

This table includes indicators of sky quality based upon the estimated artificial sky glow mosaic in absolute, relative, and index units.

The *Sky Quality Index* is a synthetic index derived from the distribution of sky luminance values in the artificial sky glow mosaic. Its range is 0-100, where 100 is a sky free of artificial sky glow. Values of 80-100 may be considered to represent skies that retain all of the natural characteristics throughout most of the sky, 60-80 retaining most of the natural sky features, but only in areas within 40 degrees of the zenith, 40-60 represents skies where the Milky Way is not visible or only the brightest parts are visible near the zenith, 20-40 represents skies only stars and planets remaining and the land is illuminated at a level of moonlight, and 0-20 indicates only the brightest stars remain, and the land is in perpetual twilight.

The *Average Sky Luminance, Zenith Luminance,* and the *Brightest square degree* are reported as in the all sources table, but in linear units only. The whole sky mosaic is clipped at 80 degrees zenith angle and 70 degrees and an average sky luminance computed for each in order to provide a more unbiased comparison to areas that may have blocked horizons.

The *All-sky Light Pollution Ratio* (ALR) is the most important indicator of light pollution from artificial sky glow. It is merely the ratio of the all-sky average luminance from artificial sources to the natural reference condition of 250 μcd m^{-2}. This unit-less ratio may be easily interpreted is a linear measure of the amount of light from sky brightness above the natural background. For example an ALR of 1.0 indicates there is 100% more light in the environment than natural conditions, 2.0 = 200%, 0.5 = 50%, etc.

The *Total Luminous Emittance* from artificial sky glow express in magnitudes may be compared to astronomical objects such as Sirius or Jupiter (-2), Venus (-4), a thin crescent moon (-7), or the moon at other phases as described above.

Horizontal and *Maximum Vertical Illuminance* are reported as in the all sources table. These values may also be compared to the reference condition of 0.8 mlux and 0.4 mlux, respectively.

References

Duriscoe, D.M. "Photometric indicators of visual night sky quality derived from all-sky brightness maps." Journal of Quantitative Spectroscopy and Radiative Transfer (2016), http://dx.doi.org/10.1016/j.jqsrt.2016.02.022.

DARK SKY PARTNERS SKY BRIGHTNESS MEASUREMENTS REPORT

MCAGCC170224 MCAGCC **Sand Hill** **24-Feb-17**

Data Night Attributes

Longitude:	-116.25573	Camera:	FLI 16803	Air temp. (C):	4.7	ZLM:	6.50	OBS_1:	D Duriscoe
Latitude:	34.31028	# of sets:	3	R. H. (%):	48.0	BORTLE:	4	OBS_2:	J Kosa
Elevation (m):	768	Exposure (secs):	16	Wind Speed (mph):	13	SQM:		OBS_3:	E Adams

NARRATIVE: Site near water well pump building and air quality station. Seeing good transparency very good. While areas near the zenith give a hint of excellent sky quality, the horizon from west through south to east contains enough light pollution to make dark adaptation impossible unless facing north. The Milky Way is easily visible, with details in Auriga and Gemini visible early, but as it sets to the west later the detail disappear. To the south it is diminished by sky glow in Canis Major and disappears in Puppis. An area of only 25 degrees in diameter near the zenith contains no gradient, otherwise glow from the west (San Bernardino/ Los Angeles area) extends all the way from horizon to zenith. Light trespass from HPS lamps at ordnance bunkers on the base to the east 10 miles away are the brightest objects in view, along with some unshielded LED streetlights at the Mainside development. Twentynine Palms, Joshua Tree, and Yucca valley are shielded by hills blocking light trespass, while sky glow from Joshua Tree and Yucca Valley blend with more distant and larger cities. ZLM 6.2 early, barely observing 6.5 later in Ursa Major. Las Vegas light dome easily visilbe but not nearly as bright as the L.A. area or the Mainside development.

Data Set Attributes

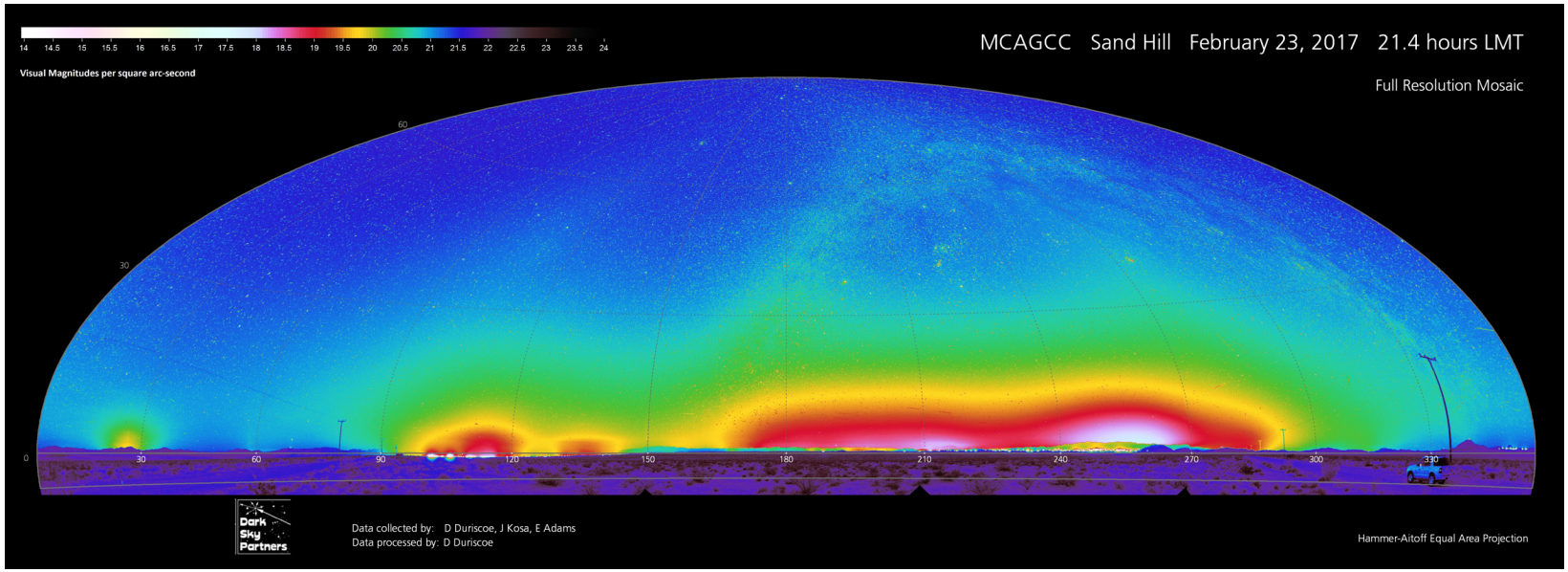
	Quality Flags				Natural Sky Model			Extinction				Collection Properties			
Data Set	Use-able	Col-lection	Pro-cessing	Atmo-sphere:	Zenith airglow (µcd/m²)	Fit quality	Natural sky model fit notes	Ext. coeff. (mag/ airmass)	Std err Y	# stars used	# stars reject	% Clouds	Ave. Point Error	Max Point Error	total bias drift
1	Y	4	5	4	89	4	airglow a guess, good fit	0.178	0.04	62	0	0	2.42	3.11	0.5
2	Y	4	5	4	89	4	airglow may have increased slightly	0.182	0.04	61	0	0	2.01	3.08	0.5
3	Y	4	5	4	89	5		0.174	0.03	66	0	0	2.14	3.01	1.0

Populated Places

Place	Population (2010)	Distance (km)	Azimuth	Walker's	Apparent Half-Width (degrees)
Twentynine Palms city	25,048	25.1	136	0.795	15.6
Los Angeles city	3,792,621	200.8	261	0.664	5.6
Yucca Valley town	20,700	25.8	216	0.613	12.6
Joshua Tree CDP	7,414	21.5	194	0.344	14.4
Homestead Valley CDP	3,032	15.2	254	0.339	19.2
San Diego city	1,307,402	185.0	206	0.281	5.1
Indio city	76,036	64.5	178	0.227	4.3
Riverside city	303,871	112.5	249	0.226	4.2
San Bernardino city	209,924	97.4	259	0.224	4.1
Cathedral City city	51,200	56.1	200	0.217	4.3
Moreno Valley city	193,365	97.4	244	0.207	3.8
Desert Hot Springs city	25,938	46.7	215	0.174	5.4
Palm Desert city	48,445	64.3	189	0.146	4.2
Palm Springs city	44,552	62.3	205	0.146	8.0
Fontana city	196,069	113.1	259	0.144	3.0
Anaheim city	336,265	147.4	250	0.128	2.5
Victorville city	115,903	103.5	284	0.106	4.3
Long Beach city	462,257	183.5	253	0.101	2.0
Coachella city	40,704	69.6	172	0.101	4.0
Rancho Cucamonga city	165,269	122.0	261	0.101	2.7
Santa Ana city	324,528	162.8	247	0.096	1.7
Hesperia city	90,173	97.7	276	0.096	4.5
Hemet city	78,657	93.3	227	0.093	2.9
Yucaipa city	51,367	78.8	247	0.093	3.5
Redlands city	68,747	88.9	251	0.092	3.5
Ontario city	163,924	128.0	257	0.088	2.9
Apple Valley town	69,135	90.9	286	0.088	4.9
Rialto city	99,171	106.4	258	0.085	2.3
La Quinta city	37,467	74.3	181	0.079	4.1
Corona city	152,374	130.3	248	0.079	2.5
Highland city	53,104	86.4	255	0.077	2.6
Las Vegas city	583,756	231.3	23	0.072	2.6
Irvine city	212,375	156.3	244	0.070	2.7
Big Bear City CDP	12,304	50.0	263	0.070	5.9
Banning city	29,603	71.7	236	0.068	3.5

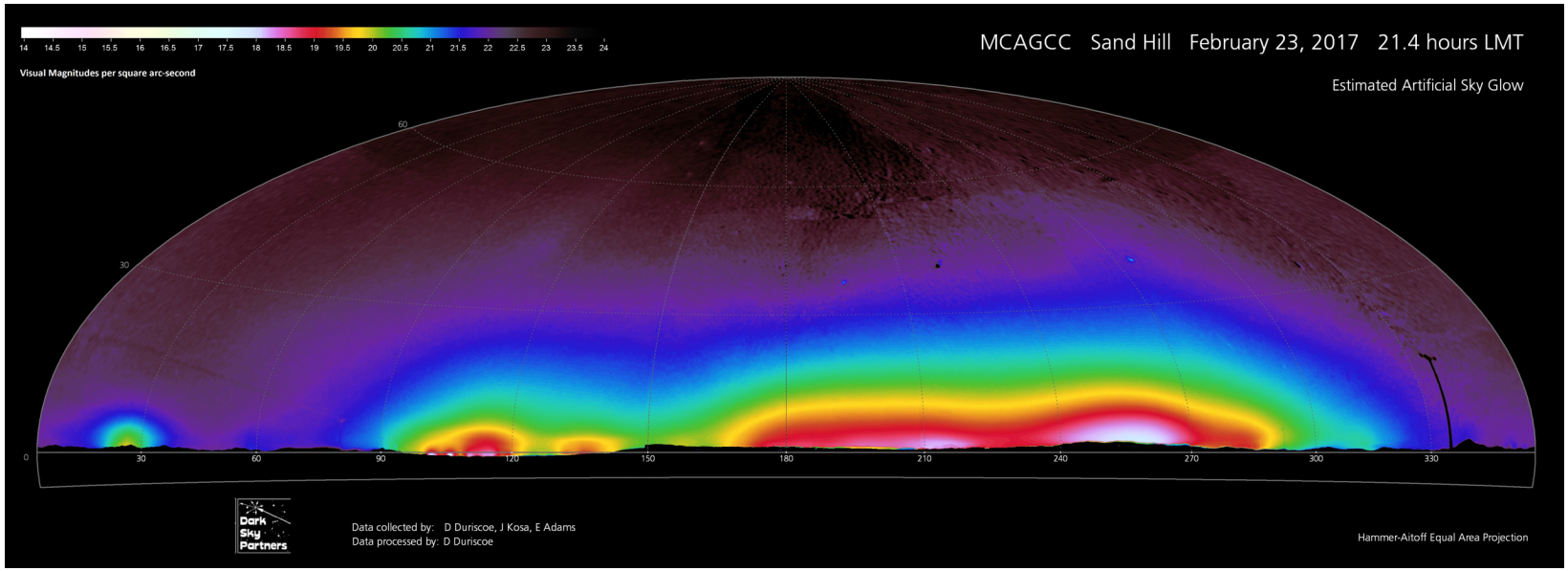
Murrieta city	103,466	119.0	227	0.067	2.5
Temecula city	100,097	120.4	222	0.063	2.4
Pomona city	149,058	141.2	259	0.063	1.8
Beaumont city	36,877	81.0	232	0.062	3.6
Menifee city	77,519	109.9	231	0.061	3.2
San Jacinto city	44,199	88.7	230	0.060	3.0
Perris city	68,386	106.1	237	0.059	2.7
Oceanside city	167,086	154.8	219	0.056	2.2
Rancho Mirage city	17,218	63.2	195	0.054	4.1
Escondido city	143,911	151.0	210	0.051	2.1

MCAGCC170224 Date (LMT) 23-Feb-17 Time (LMT): 21.44



PHOTOMETRY OF ALL SOURCES

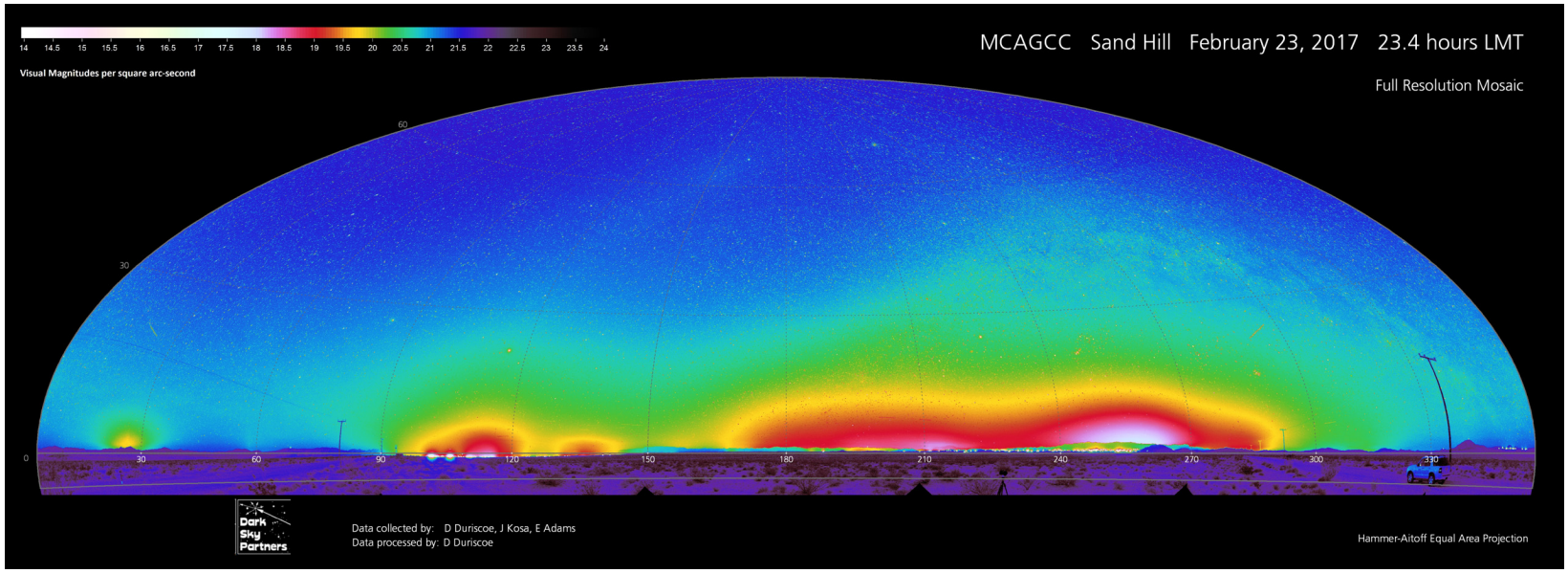
Average Sky Luminance (mag arcsec-²)	Average Sky Luminance (µcd/m²)	Zenith Luminance (mag arcsec-²)	Zenith Luminance (µcd/m²)	Brightest square degree (mag arcsec-²)	Brightest square degree (µcd/m²)	Synthetic SQM (mag arcsec-²)	Total luminous emittance (mags)	Illuminance (mlux) Horizontal	Illuminance (mlux) Max Vert
20.57	640	21.50	274	18.63	3,765	21.23	-8.01	1.367	1.714



PHOTOMETRY OF ARTIFICIAL SKYGLOW

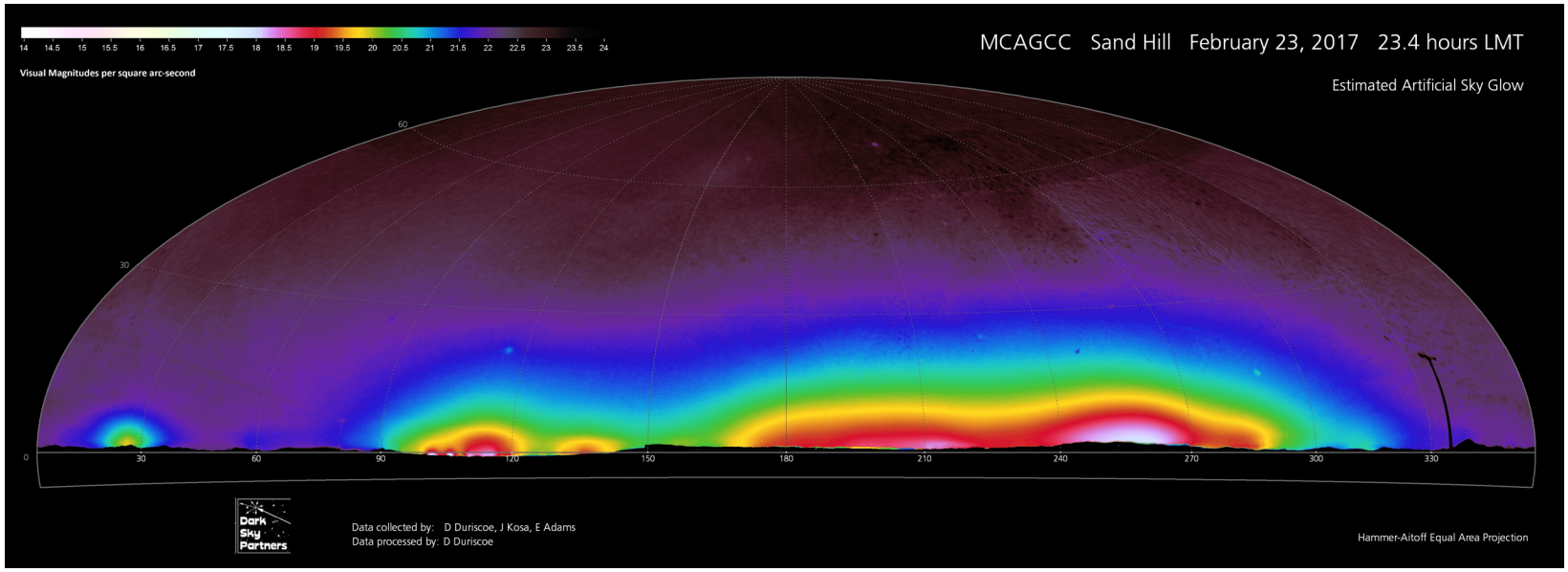
Sky Quality Index (SQI)	Average Sky Luminance (µcd/m²)	Average Sky Luminance to zenith angle 80°	Average Sky Luminance to zenith angle 70°	Zenith Luminance	Brightest lumininance (µcd/m²)	All-sky light pollution ratio (ALR)	Total luminous emittance (mags)	Illuminance (mlux) Horizontal	Illuminance (mlux) Max Vert
60.0	361	193.8	128.1	38	3,520	1.45	-7.36	0.520	1.209

MCAGCC170224 Date (LMT) 23-Feb-17 Time (LMT): 23.43



PHOTOMETRY OF ALL SOURCES

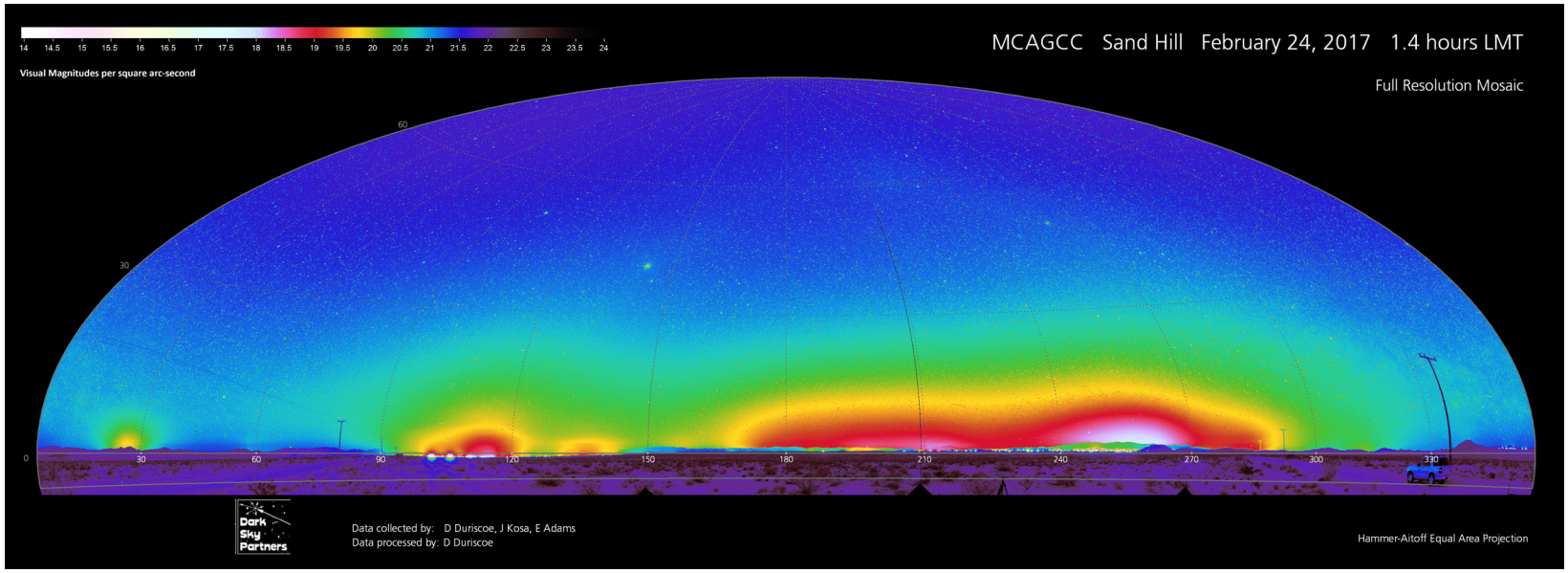
Average Sky Luminance (mag arcsec-²)	Average Sky Luminance (µcd/m²)	Zenith Luminance (mag arcsec-²)	Zenith Luminance (µcd/m²)	Brightest square degree (mag arcsec-²)	Brightest square degree (µcd/m²)	Synthetic SQM (mag arcsec-²)	Total luminous emittance (mags)	Illuminance (mlux) Horizontal	Illuminance (mlux) Max Vert
20.64	600	21.55	259	18.78	3,301	21.30	-7.95	1.298	1.559



PHOTOMETRY OF ARTIFICIAL SKYGLOW

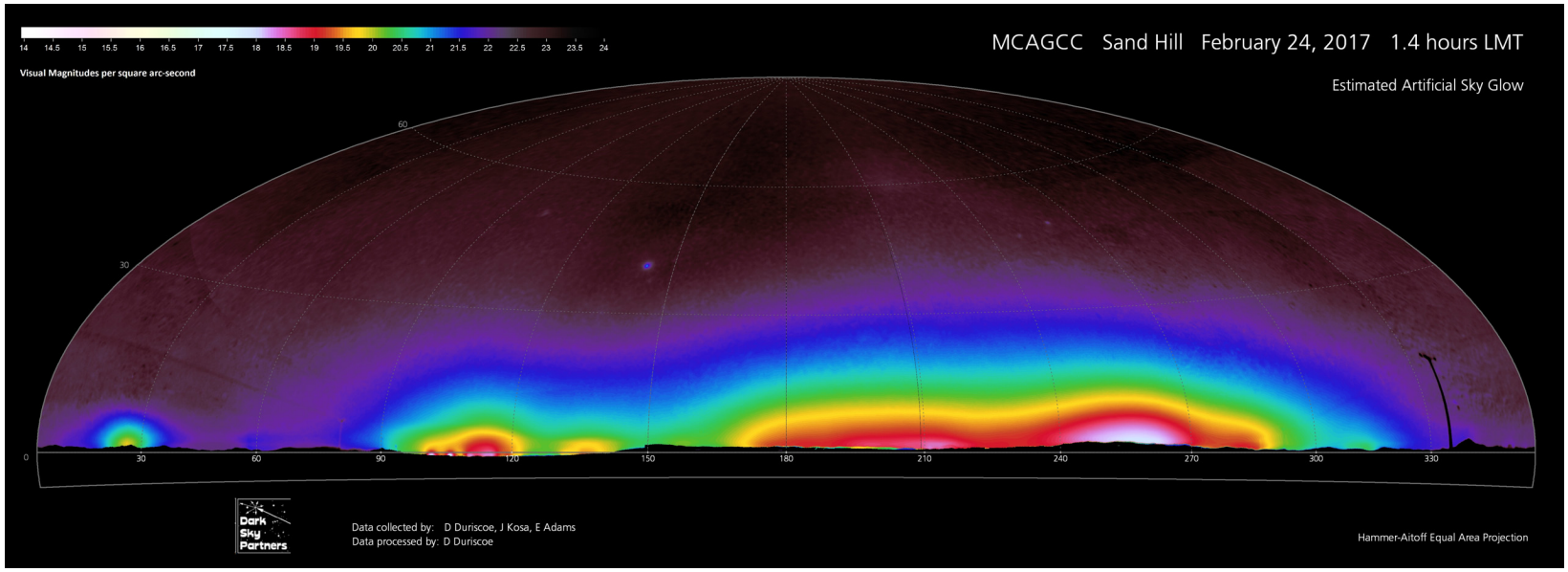
Sky Quality Index (SQI)	Average Sky Luminance (µcd/m²)	Average Sky Luminance to zenith angle 80°	Average Sky Luminance to zenith angle 70°	Zenith Luminance	Brightest luminiance (µcd/m²)	All-sky light pollution ratio (ALR)	Total luminous emittance (mags)	Illuminance (mlux) Horizontal	Illuminance (mlux) Max Vert
60.8	322	175.7	120.2	52	3,047	1.30	-7.23	0.480	1.034

MCAGCC170224 Date (LMT) 24-Feb-17 Time (LMT): 1.43



PHOTOMETRY OF ALL SOURCES

Average Sky Luminance (mag arcsec-²)	Average Sky Luminance (µcd/m²)	Zenith Luminance (mag arcsec-²)	Zenith Luminance (µcd/m²)	Brightest square degree (mag arcsec-²)	Brightest square degree (µcd/m²)	Synthetic SQM (mag arcsec-²)	Total luminous emittance (mags)	Illuminance (mlux) Horizontal	Illuminance (mlux) Max Vert
20.71	564	21.69	229	18.81	3,202	21.43	-7.88	1.184	1.469



PHOTOMETRY OF ARTIFICIAL SKYGLOW

Sky Quality Index (SQI)	Average Sky Luminance (µcd/m²)	Average Sky Luminance to zenith angle 80°	Average Sky Luminance to zenith angle 70°	Zenith Luminance	Brightest luminiance (µcd/m²)	All-sky light pollution ratio (ALR)	Total luminous emittance (mags)	Illuminance (mlux) Horizontal	Illuminance (mlux) Max Vert
65.5	288	146.4	93.8	49	2,935	1.16	-7.11	0.398	0.971

DARK SKY PARTNERS SKY BRIGHTNESS MEASUREMENTS REPORT

MCAGCC170225 MCAGCC **Sand Hill** **25-Feb-17**

Data Night Attributes

Longitude:	-116.25432	Camera:	FLI 16803	Air temp. (C):	5.6	ZLM:	6.50	OBS_1:	D Duriscoe
Latitude:	34.31024	# of sets:	3	R. H. (%):	42.5	BORTLE:	4	OBS_2:	J Kosa
Elevation (m):	770	Exposure (secs):	16	Wind Speed (mph):	3	SQM:	21.60	OBS_3:	E Adams

NARRATIVE: Same site as previous night, seeing very good, transparency very good, but some haze observed in daytime. Cities to the west and south are the most serious impact to the sky quality, preventing dark adaptation unless looking north. As the evening progresses, the sky darkens noticably, after midnight there is an area north of the zenith that appears to be nearly free of sky glow, but ZLM is no better than 6.5 (with effort). Gegenschein barely glimpsed near Regulus, but not at all obvious, Zodiacal light is lost in the glow to the west. The Milky Way has some detail when overhead, but at it sets both the sky glow and extinction from haze diminish it greatly. SQM 21.42 after first set, 21.65 after last.

Data Set Attributes

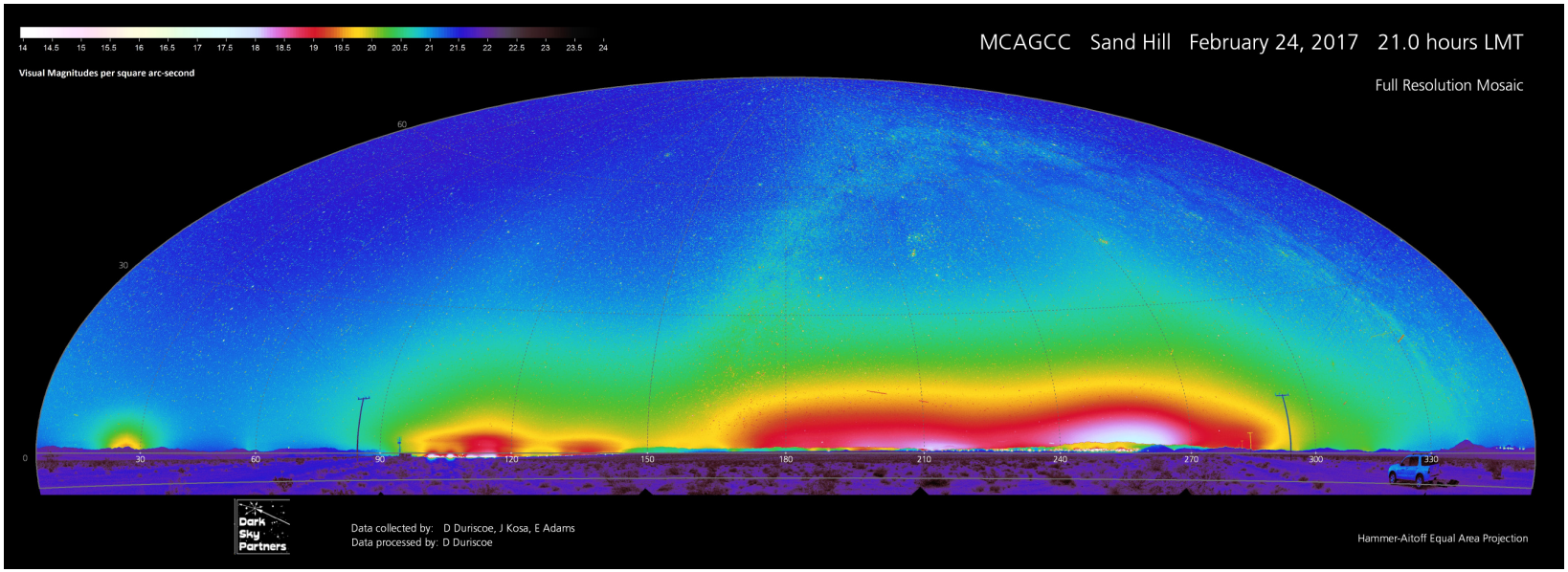
	Quality Flags				Natural Sky Model			Extinction				Collection Properties			
Data Set	Use-able	Col-lection	Pro-cessing	Atmo-sphere:	Zenith airglow (μcd/m²)	Fit quality	Natural sky model fit notes	Ext. coeff. (mag/ airmass)	Std err Y	# stars used	# stars reject	% Clouds	Ave. Point Error	Max Point Error	total bias drift
1	Y	4	5	4	89	4	airglow a guess, good fit, milky way slightly oversubstract	0.189	0.04	72	0	0	1.95	2.41	0.7
2	Y	4	5	4	95	5	increased airglow at zenith	0.188	0.03	62	0	0	2.07	2.46	1.1
3	Y	4	5	4	102	5	gegenschein does not subtract perfectly	0.191	0.03	64	0	0	1.78	2.47	0.7

Populated Places

Place	Population (2010)	Distance (km)	Azimuth	Walker's	Apparent Half-Width (degrees)
Twentynine Palms city	25,048	25.0	136	0.802	15.6
Los Angeles city	3,792,621	200.9	261	0.663	5.6
Yucca Valley town	20,700	25.9	216	0.609	12.5
Joshua Tree CDP	7,414	21.6	195	0.343	14.4
Homestead Valley CDP	3,032	15.3	254	0.332	19.1
San Diego city	1,307,402	185.1	206	0.281	5.1
Indio city	76,036	64.5	178	0.228	4.3
Riverside city	303,871	112.6	249	0.226	4.2
San Bernardino city	209,924	97.5	259	0.224	4.1
Cathedral City city	51,200	56.1	200	0.217	4.3
Moreno Valley city	193,365	97.5	244	0.206	3.8
Desert Hot Springs city	25,938	46.8	216	0.173	5.4
Palm Desert city	48,445	64.3	189	0.146	4.2
Palm Springs city	44,552	62.3	205	0.145	8.0
Fontana city	196,069	113.3	259	0.144	3.0
Anaheim city	336,265	147.5	250	0.127	2.5
Victorville city	115,903	103.6	284	0.106	4.3
Long Beach city	462,257	183.6	253	0.101	2.0
Coachella city	40,704	69.5	172	0.101	4.0
Rancho Cucamonga city	165,269	122.1	261	0.100	2.7
Santa Ana city	324,528	162.9	247	0.096	1.7
Hesperia city	90,173	97.8	276	0.095	4.5
Hemet city	78,657	93.4	227	0.093	2.9
Yucaipa city	51,367	79.0	247	0.093	3.5
Redlands city	68,747	89.0	251	0.092	3.5
Ontario city	163,924	128.1	257	0.088	2.9
Apple Valley town	69,135	91.1	286	0.087	4.9
Rialto city	99,171	106.5	258	0.085	2.3
La Quinta city	37,467	74.3	181	0.079	4.1
Corona city	152,374	130.4	248	0.078	2.5
Highland city	53,104	86.5	255	0.076	2.6
Las Vegas city	583,756	231.2	23	0.072	2.6
Irvine city	212,375	156.4	244	0.069	2.7
Big Bear City CDP	12,304	50.2	263	0.069	5.8
Banning city	29,603	71.8	236	0.068	3.5

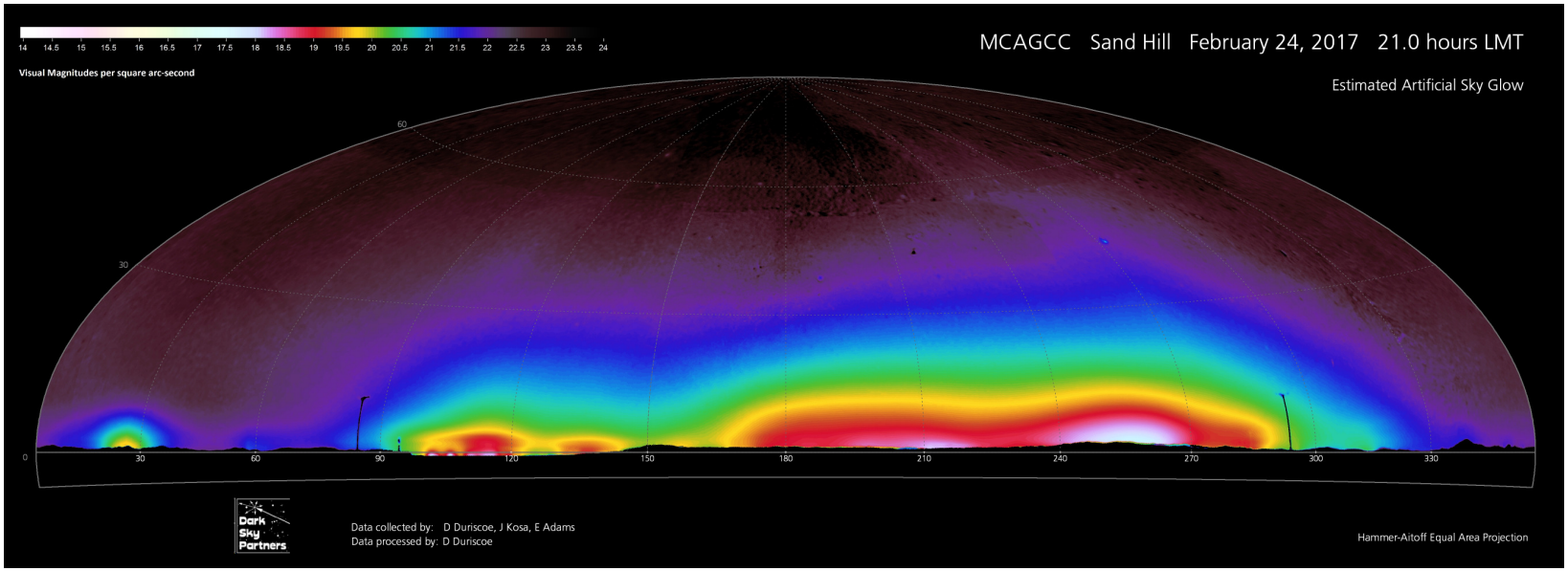
Murrieta city	103,466	119.1	227	0.067	2.5
Temecula city	100,097	120.5	222	0.063	2.4
Pomona city	149,058	141.3	259	0.063	1.8
Beaumont city	36,877	81.1	232	0.062	3.6
Menifee city	77,519	110.0	231	0.061	3.2
San Jacinto city	44,199	88.8	230	0.059	3.0
Perris city	68,386	106.2	237	0.059	2.7
Oceanside city	167,086	154.9	219	0.056	2.2
Rancho Mirage city	17,218	63.2	195	0.054	4.1
Escondido city	143,911	151.1	210	0.051	2.1

MCAGCC170225 Date (LMT) 24-Feb-17 Time (LMT): 21.04



PHOTOMETRY OF ALL SOURCES

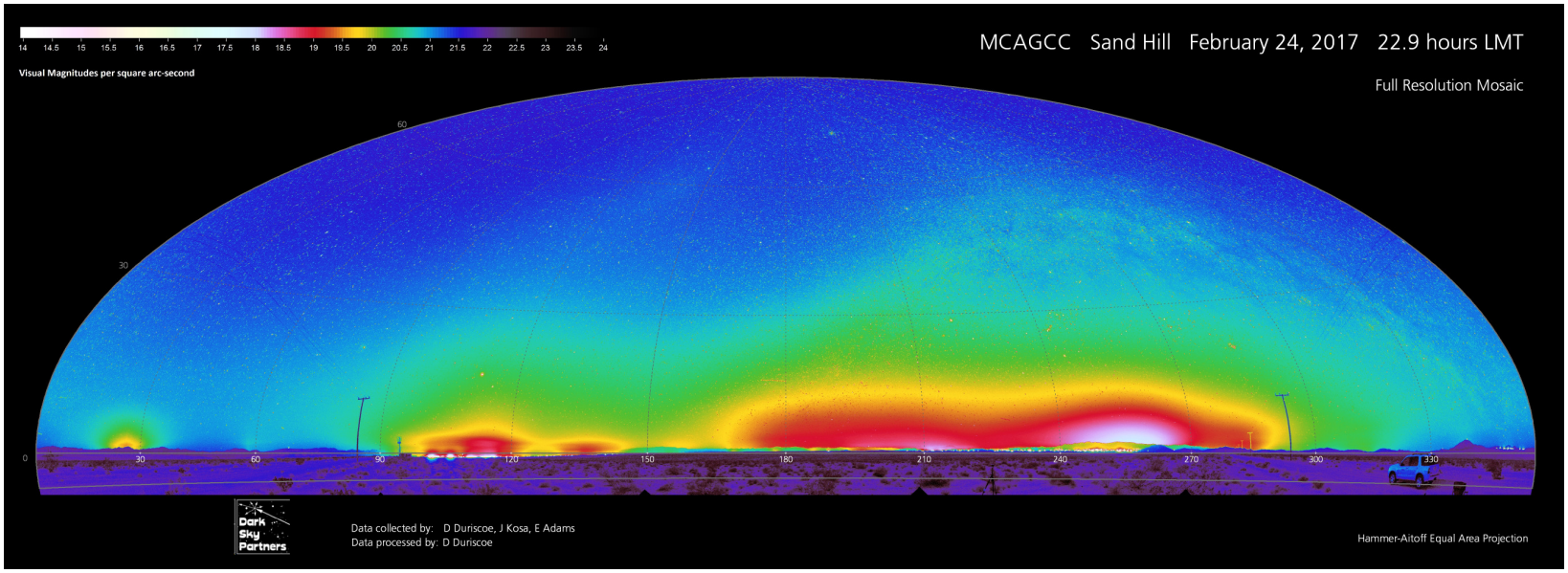
Average Sky Luminance (mag arcsec-²)	Average Sky Luminance (µcd/m²)	Zenith Luminance (mag arcsec-²)	Zenith Luminance (µcd/m²)	Brightest square degree (mag arcsec-²)	Brightest square degree (µcd/m²)	Synthetic SQM (mag arcsec-²)	Total luminous emittance (mags)	Illuminance (mlux) Horizontal	Illuminance (mlux) Max Vert
20.57	642	21.45	285	18.64	3,760	21.24	-8.02	1.360	1.758



PHOTOMETRY OF ARTIFICIAL SKYGLOW

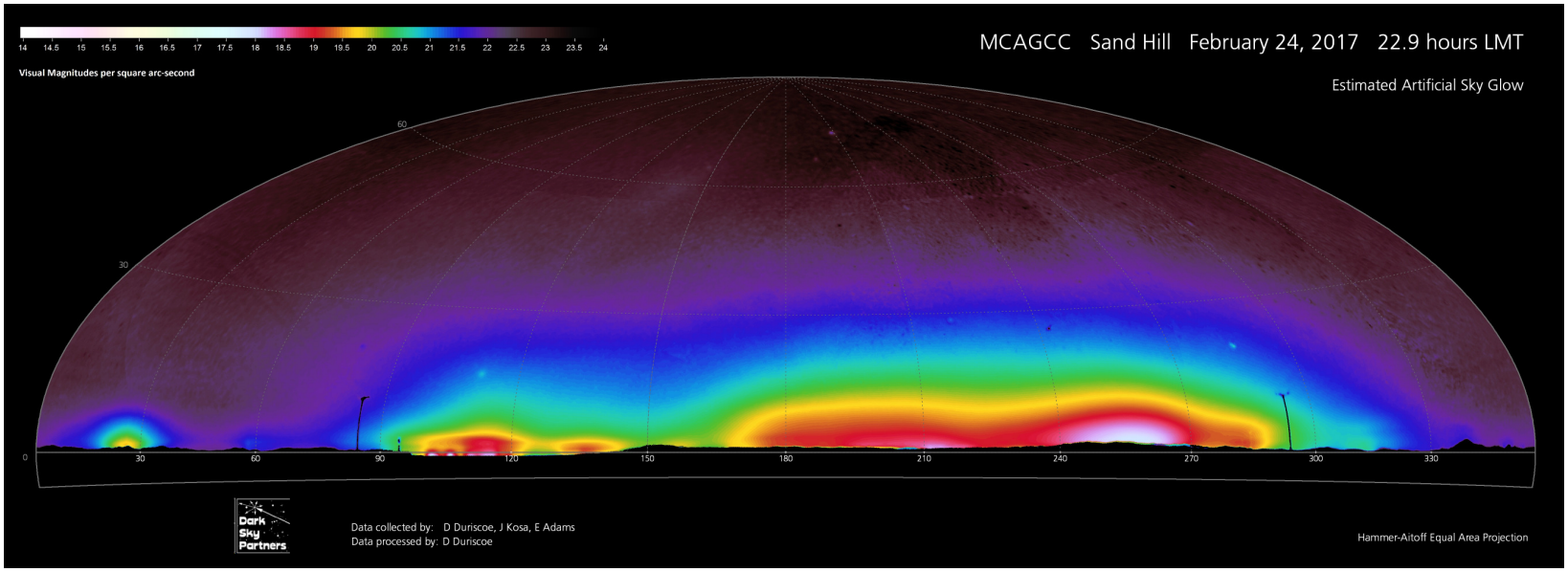
Sky Quality Index (SQI)	Average Sky Luminance (µcd/m²)	Average Sky Luminance to zenith angle 80°	Average Sky Luminance to zenith angle 70°	Zenith Luminance	Brightest lumininance (µcd/m²)	All-sky light pollution ratio (ALR)	Total luminous emittance (mags)	Illuminance (mlux) Horizontal	Illuminance (mlux) Max Vert
61.3	364	191.6	123.7	35	3,507	1.47	-7.36	0.511	1.253

MCAGCC170225 Date (LMT) 24-Feb-17 Time (LMT): 22.91



PHOTOMETRY OF ALL SOURCES

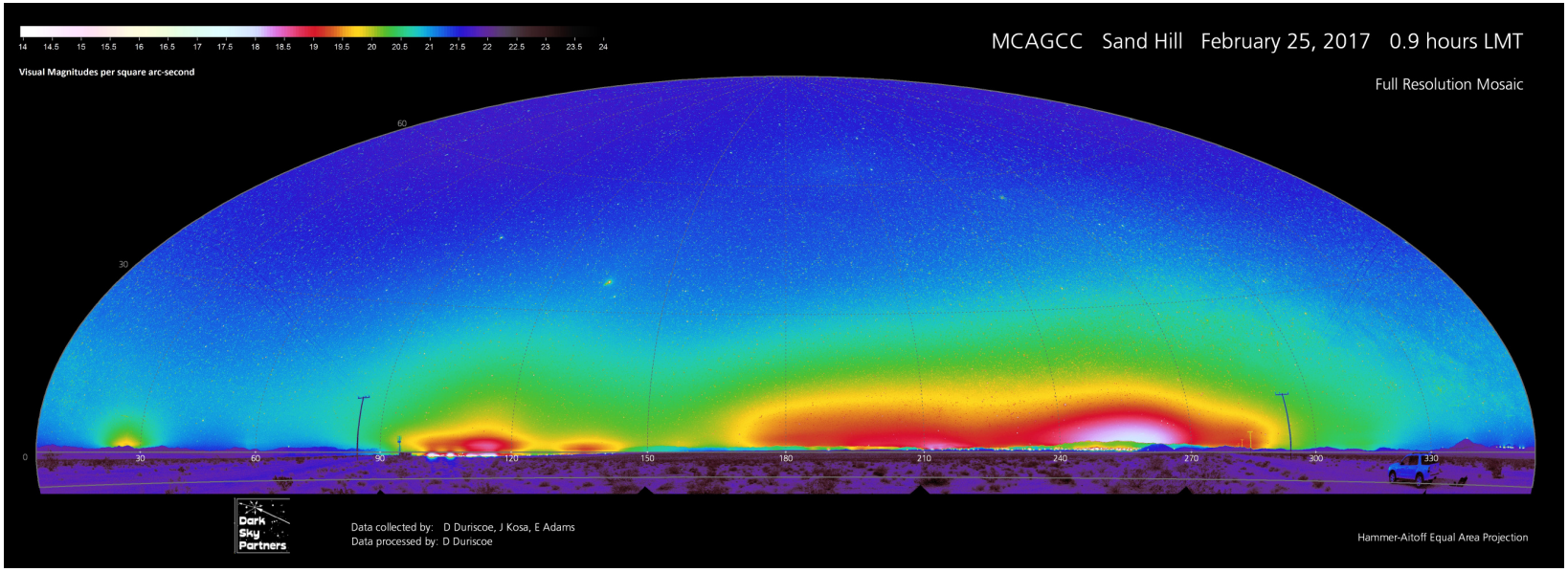
Average Sky Luminance (mag arcsec-²)	Average Sky Luminance (µcd/m²)	Zenith Luminance (mag arcsec-²)	Zenith Luminance (µcd/m²)	Brightest square degree (mag arcsec-²)	Brightest square degree (µcd/m²)	Synthetic SQM (mag arcsec-²)	Total luminous emittance (mags)	Illuminance (mlux) Horizontal	Illuminance (mlux) Max Vert
20.61	619	21.53	265	18.77	3,322	21.27	-7.98	1.340	1.637



PHOTOMETRY OF ARTIFICIAL SKYGLOW

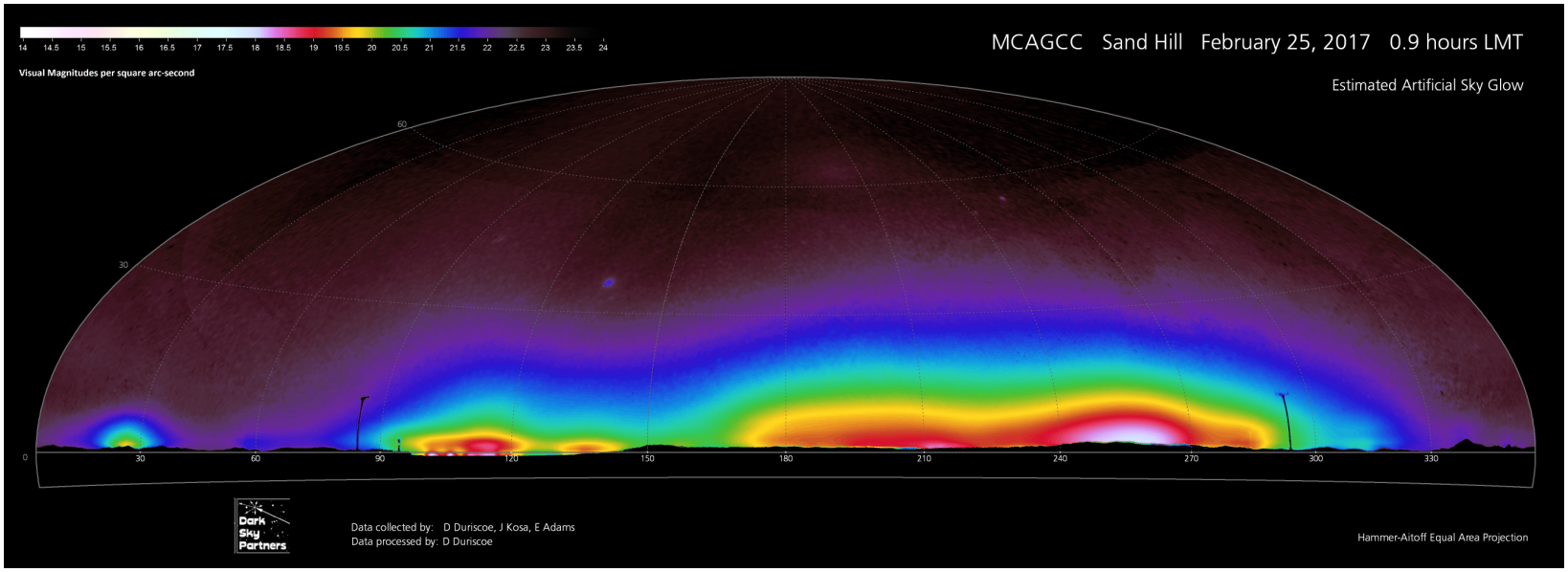
Sky Quality Index (SQI)	Average Sky Luminance (µcd/m²)	Average Sky Luminance to zenith angle 80°	Average Sky Luminance to zenith angle 70°	Zenith Luminance	Brightest lumininance (µcd/m²)	All-sky light pollution ratio (ALR)	Total luminous emittance (mags)	Illuminance (mlux) Horizontal	Illuminance (mlux) Max Vert
61.2	335	182.6	122.7	44	3,074	1.35	-7.27	0.493	1.100

MCAGCC170225 Date (LMT) 25-Feb-17 Time (LMT): 0.86



PHOTOMETRY OF ALL SOURCES

Average Sky Luminance (mag arcsec-²)	Average Sky Luminance (µcd/m²)	Zenith Luminance (mag arcsec-²)	Zenith Luminance (µcd/m²)	Brightest square degree (mag arcsec-²)	Brightest square degree (µcd/m²)	Synthetic SQM (mag arcsec-²)	Total luminous emittance (mags)	Illuminance (mlux) Horizontal	Illuminance (mlux) Max Vert
20.70	571	21.64	240	18.89	2,988	21.39	-7.89	1.224	1.476



PHOTOMETRY OF ARTIFICIAL SKYGLOW

Sky Quality Index (SQI)	Average Sky Luminance (µcd/m²)	Average Sky Luminance to zenith angle 80°	Average Sky Luminance to zenith angle 70°	Zenith Luminance	Brightest lumininance (µcd/m²)	All-sky light pollution ratio (ALR)	Total luminous emittance (mags)	Illuminance (mlux) Horizontal	Illuminance (mlux) Max Vert
66.4	280	143.4	91.3	44	2,727	1.13	-7.08	0.387	0.941