TO PRESERVE THE MAGNIFICENT DARK SKIES OF
OREGON AND DIMINISH LIGHT POLLUTION FOR THE
HEALTH, SAFETY AND WELL-BEING OF ALL LIFE

Oregon Skyglow Measurement Network
Technical Report Edition #8
Data from April 2019 to November 2023
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Abstract

The Oregon Skyglow Measurement Network, a volunteer-run project of DarkSky Oregon, has two goals - to support the certification of dark sky places and to track any change of skyglow over time. The Network currently consists of 52 operating Sky Quality Meters (SQMs) distributed around Oregon, at sites ranging from light polluted to pristine night sky locations.

The SQMs record the brightness of broadband visible light at night with a 5-minute cadence, continuously. Twenty-seven of the SQMs have been running for at least two years, the remaining meters for months to years. With the help of 30 volunteers, the dataset now contains over 10 million measurements.

The SQM measurements are processed through two different workflows, consistent with the goals of the project. In the first workflow, support of dark sky place certification, we follow astronomical convention and DarkSky International recommendations to include measurements when the sun is at least 18 degrees below the horizon, the moon is at least 10 degrees below the horizon, clouds are absent, and the Milky Way is not overhead. We also implement a static shift to the SQM data to account for the presence of a weatherproof case window and apply a serial adjustment for an apparent aging phenomenon of the SQMs.

The processed data support the continued certification of two existing dark sky places in Oregon as well as the future certification currently of twelve additional dark sky areas.

In the second workflow, we process the data to track any change of skyglow over time. To track change of skyglow over time, we employ the same data filters on the sun, moon, and clouds, along with the weatherproof window static shift and SQM aging adjustment as in the first workflow. Then, instead of discarding measurements when the Milky Way is overhead, we retain all the data and then subtract the brightness attributable to airglow caused by variation in the solar flux over time.

The clear night skies over the cities in Central Oregon and over Portland are 5x to 20x brighter, more light polluted, than the clear night skies at pristine night sky sites. On cloudy nights, the city skies are 20x to 300x brighter than cloudy nights at pristine night sky sites.

The processed data show increases of 4% to 6% per year for SQM sites in expanding cities in central Oregon. Other peripheral SQM sites show increases of 2% to 4% per year, while most remote sites tend to show little to no change in zenith skyglow per year. However, percentage changes are deceptive. Compared to nearby sites that show little change over the last few years, light pollution over the cities

of Central Oregon is increasing faster by 10x to 20x.

A new “Index of Milky Way Visibility” characterizes each SQM site according to the brightness contrast of the Milky Way compared to the adjacent night sky. This index will be of value to dark sky tourists and amateur astronomers.

Summary

Outdoor light shining upward brightens the sky at night, which is known as light pollution or skyglow. Light pollution hides the starry night sky and has negative environmental consequences for people and the wild ecosystem. State and Federal organizations measure air, water, and soil pollution, but do not directly measure light pollution. We are running a multi-year project to measure light pollution in Oregon, to bring attention to this environmental issue and to support parks and communities working toward certification as Dark Sky Places.

With support from 30 volunteer individuals and groups, we are currently measuring the absolute level of skyglow directly overhead at 52 sites around Oregon, and also track change of light pollution over time.

Two sites in Portland, Oregon show the most light pollution. The three most light-polluted sites in central Oregon, which have been running for about 4 years, show an increase of 4% to 6% per year, The long-term sites with naturally dark night skies, far from the cities, show little change in brightness of the overhead night sky.

The measurements show that the two current Dark Sky Places in Oregon, the community of Sunriver, and Prineville Reservoir State Park, retain dark skies. Measurements at sites currently working toward Dark Sky Place certification also meet Dark Sky Place criteria. These locations include Cottonwood Canyon State Park, Wallowa Lake State Park, Black Butte Ranch, Oregon Caves National Monument, the City of Sisters, the Pine Mountain Observatory and large areas of the Outback of southeastern Oregon. Measurements in the Oregon Outback document pristine night skies overhead and are the starriest night skies in Oregon.

We are expanding the network monthly. We solicit your help to install and maintain meters at additional sites. We would especially like to expand coverage in the Willamette Valley, in the Columbia River Gorge, and along the Oregon Coast.

Background

Light pollution at night has been shown to have a negative effect on people and the larger environment, in addition to being a waste of energy. Light pollution, especially blue light at night, disrupts the circadian rhythm of people and other organisms. The impact on humans includes lack of sleep and probable increase in cancers and other diseases. Various animal species – birds, amphibians, mammals, invertebrates and primates – are adversely impacted by confusion of celestial navigation, misorientation at night, attraction/repulsion to artificial light, impact on predator/prey relationships, effects on timing of breeding, nesting, migration and foraging. Here's a good presentation of this topic by DarkSky Oregon Board Member, Mary Coolidge, From the Desert to the Coast, the Case for Dark Skies.

State and Federal organizations measure air, water, and soil pollution, but do not directly measure light pollution. In part, to show what is possible, and to bring attention to this environmental issue, DarkSky Oregon, with support from other groups, is running a multi-year project to measure light pollution in Oregon. We operate a network of continuously recording Sky Quality Meters (SQMs) in Oregon.

Volunteers gather accumulated data every 3 months from the measurement sites. Every twelve months we update this report to include all data acquired to date. This report is Edition #8 and incorporates data from several new SQMs. Figure 1 shows the 52 locations from which we have SQM data in Oregon as of the date of this report. Of those, 48 are currently operating and 4 are locations where we stopped gathering data – either the SQM was moved due to access conditions or stopped operating, but we retain the existing data. Appendix A shows a chart of the time ranges of data available from the 52 SQM sites with data up to the November 2023 deadline of this report.

The brightness of the night sky is due to contributions from both man-made artificial light and natural light. SQMs measure the brightness of the night sky directly overhead and provide a measure of both light pollution and natural light at night. SQMs are widely used around the world for this kind of survey (Kyba and others, 2015).

Other measurement tools designed to measure skyglow, such as calibrated all-sky cameras (Jechow and others, 2017), provide additional information about skyglow, namely a complete picture of how the skyglow varies across the sky at a given location. Our SQM measurements document the skyglow directly above. Changes of skyglow may be more readily identified by including measurements nearer the horizon. We anticipate augmenting the SQM zenith measurements by all-sky camera data going forward.

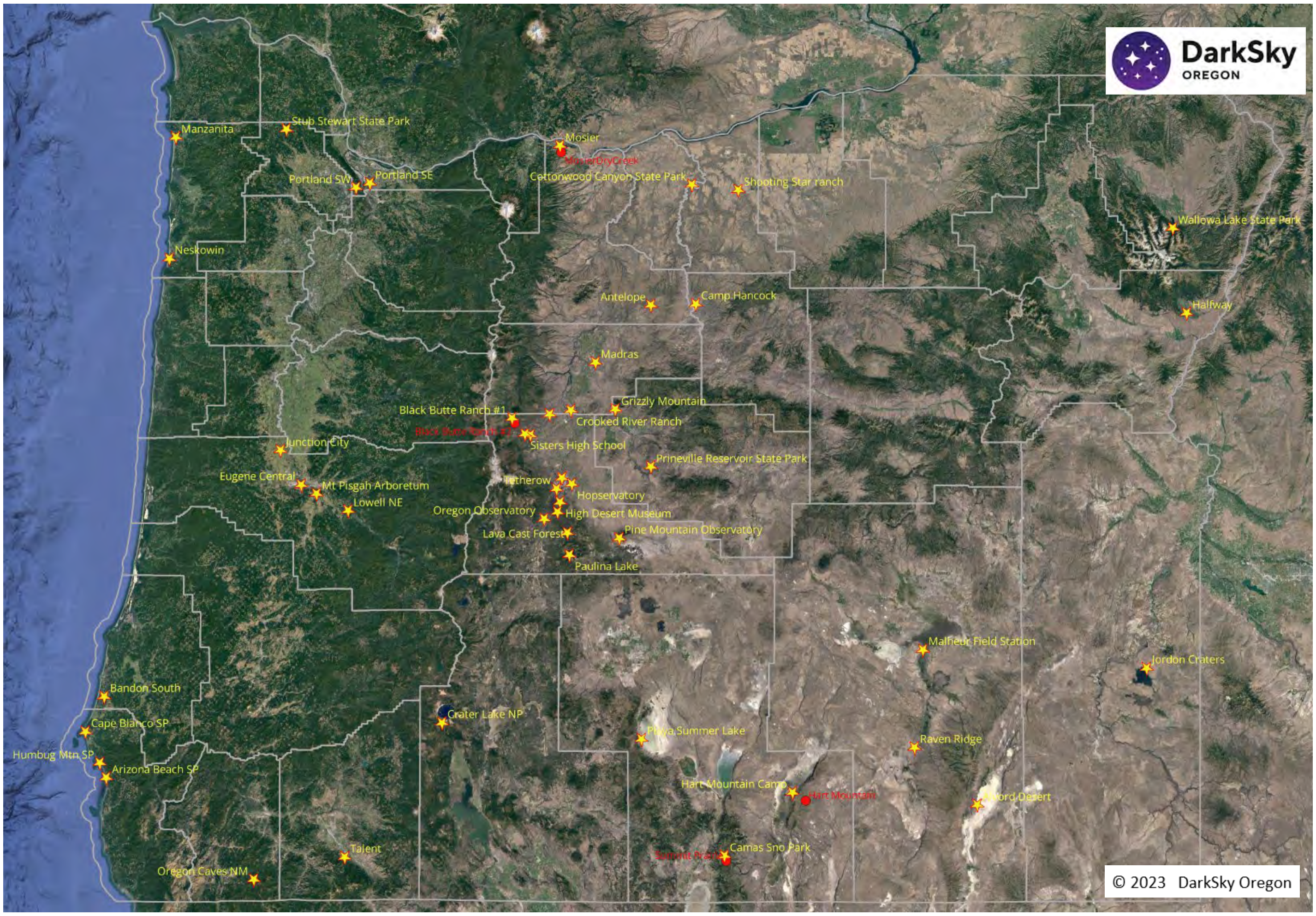


Figure 1. *Yellow stars show the locations of the 48 SQM monitoring sites in Oregon as of the date of this report. Four sites marked by red circles have been decommissioned. The gray outlines demark the counties of Oregon. The background image, from Google Earth, is 450 miles across, from west to east.*

Explanation of Skyglow Measurements

Each SQM is enclosed inside a weatherproof case and is attached to a fixed support, pointed directly upwards. The SQMs are set to record a skyglow measurement every five minutes. Figure 2 shows examples of SQMs installed at various sites in Oregon.

Figure 2. *Examples of SQMs installed at sites in Oregon. The meter resides inside a weatherproof case and points vertically toward the sky.*

Figure 3 shows typical data from five SQMs during the night of August 1-2, 2019, which was a mostly cloud-free night during a new moon period.

Data units in Figure 3 and elsewhere in this report are in a logarithmic scale used by astronomers -- magnitudes per arc second squared (mags/arcsecond^2). This unit of measure, for example, 21.5 mags/arcsecond^2, is like saying that the sky glows as though the light of one 21.5-magnitude star, a very dim star, was spread across each square arcsecond (a very small 2-dimensional area) of sky. Because this scale is logarithmic, small changes in value of mags/arcsecond^2 represent larger changes in a linear brightness scale. We convert the skyglow measurements to a linear scale prior to statistical adjustments for various effects. See Table 1 below for additional information.

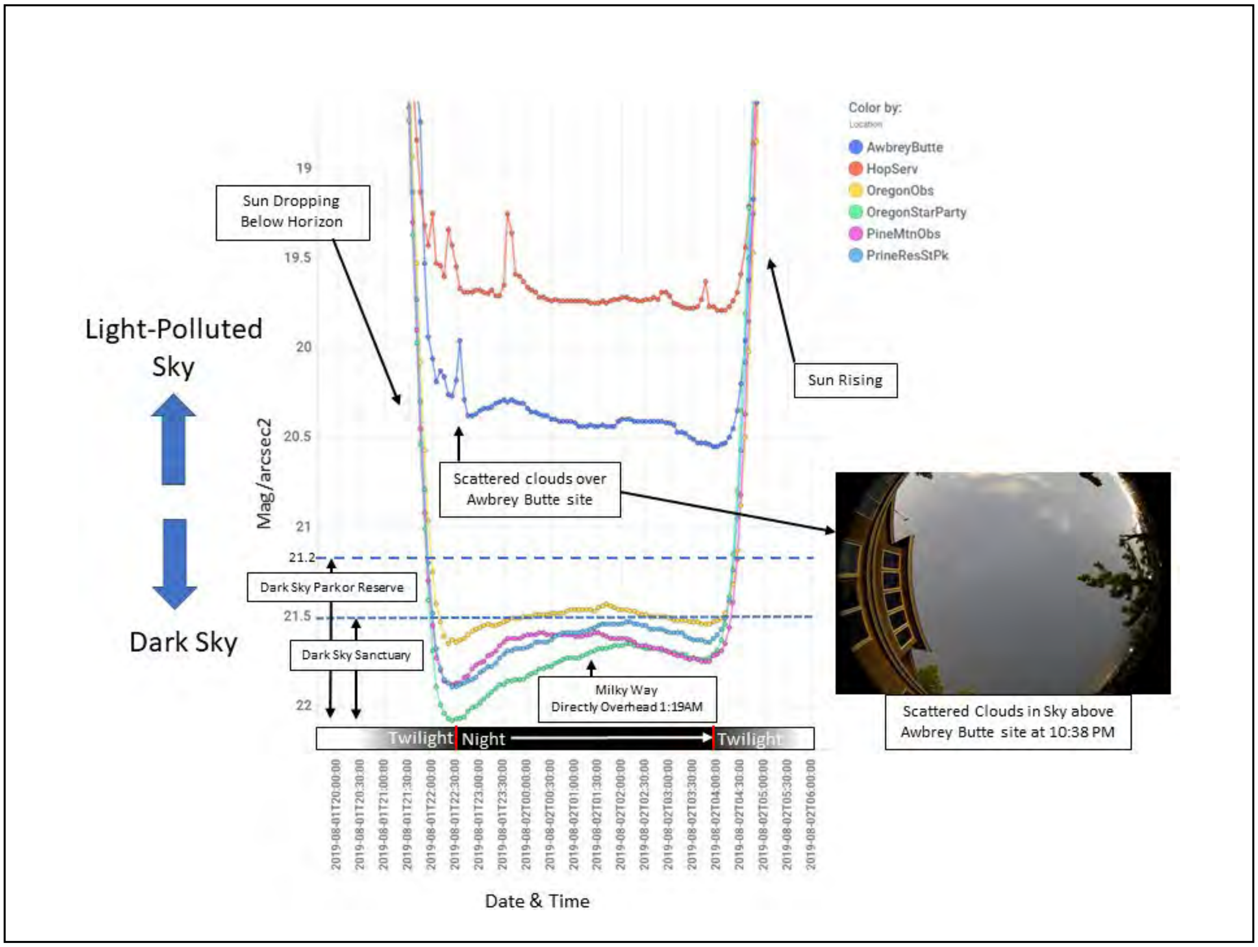


Figure 3. *Typical data from SQMs at six different locations for the same single night of August 1-2, 2019.*

The vertical axis in Figure 3 displays the SQM measurements – larger numbers are toward the bottom and represent measurements of darker sky. The horizontal axis is Date and Time, over the night of August 1-2, 2019, with labels one hour apart. The colored lines show the recorded data from five SQM locations and additional data recorded at a temporary site during the Oregon Star Party at Indian Trail Spring – the green line.

The data in Figure 3 show that the night sky, directly overhead at the Hopservatory and Awbrey Butte sites (the uppermost red and blue lines), are light-polluted compared to the other sites. These two light-polluted sites are located within the light-dome over the city of Bend. The other four sites have darker skies – they are far away from light-polluted cities. The Oregon Star Party site east of Prineville (green line) had the darkest night sky among these six locations on August 1 – 2 and is furthest of all the sites from the Central Oregon cities.

DarkSky International has a program to recognize areas that are still mostly unaffected by light pollution. Three categories of such dark sky places are known as Dark Sky Parks, Reserves and Sanctuaries. As shown by the horizontal dashed lines, Figure 3, a Dark Sky Park or Reserve must have SQM readings of at least 21.2 mags/arcsecond^2. Dark Sky Sanctuaries must meet a stricter night sky darkness of at least 21.5 mags/arcsecond^2. The data suggest that all four of the darkest Central Oregon SQM locations in Figure 3 may meet the stricter criterion. In fact, Prineville Reservoir State Park is now certified as the first Dark Sky Park in Oregon. Note that other significant criteria must also be met to obtain status as a Dark Sky Park, Dark Sky Reserve or Dark Sky Sanctuary.

Figure 3 shows that the sky overhead at the four dark sites brightens as the Milky Way rises directly overhead, and then darkens as the Milky Way begins descending through the early morning hours. The effect of the Milky Way brightening in the data for the two sites under the City of Bend light dome (Awbrey Butte and Hopservatory), is not obvious because the Milky Way is washed out by the light-polluted skies at those two sites. Instead, we see a gradual darkening through the night hours, which we presume is due to some outdoor lights in the City, being dimmed or turned off, and fewer car headlights as most people are sleeping.

Project Goals & Data Processing Steps

This project has two main Goals: 1) to support certification of Dark Sky Places and 2) to document the level of light pollution and to track its change over time. Processing of the SQM data differs according to these goals, as described below.

Under Goal #1, the skyglow data support local efforts to nominate sites under the DarkSky International DarkSky Places program. So far, these Oregon data have been instrumental in helping to certify the community of Sunriver as a Dark Sky Development of Distinction (Aug 2020) and Prineville Reservoir State Park as the first Dark Sky Park in Oregon (May 2021). Nighttime measurements are currently underway at eight other potential Dark Sky Parks in Oregon -- Cottonwood Canyon, Wallowa Lake, Cape Blanco, Humbug Mountain, Arizona Beach State Parks – and at Oregon Caves National Monument, Pine Mountain Observatory and Newberry National Volcanic Monument.

Volunteers are also measuring skyglow at potential Dark Sky Communities in Oregon – Black Butte Ranch, the City of Sisters, the City of Antelope and Halfway. The skyglow data processed by DarkSky Oregon from eight sites in southeastern Oregon were submitted to DarkSky International by the Oregon Outback Dark Sky Network in support of certification of a Dark Sky Sanctuary in that large area.

Under Goal #2, we want to document changes in light pollution over a multi-year period at each site. As scientific measurements, the skyglow data will inform responsible local officials of the level of the light pollution problem, ideally leading to change for healthier and safer communities. DarkSky International has identified five principles of responsible outdoor lighting which, when followed, will reduce light pollution.

Processing of the SQM data for Goals #1 and #2 begins with the same first steps, and then diverges in subsequent steps to accommodate each of the two project goals.

Goal #1 - We process the SQM data suitable for Dark Sky Place certification along these steps:

1) Eliminate data influenced by the sun, moon and clouds
2) Adjust data for SQM hardware conditions – presence of the weather proof case and aging of the SQM
3) Exclude any data values greater than 22.0 or 22.1 magnitudes per arc second squared, depending on the site
4) Minimize influence of the brightness of the Milky Way – filter out data acquired when the Milky Way is overhead

Goal #2 - We process data for the level of light pollution and detection of long-term change of skyglow due to artificial sources, along these steps:

1) Same as for Goal #1
2) Same as for Goal #1
3) Same as for Goal #1
4) Keep all of the data, irrespective of the position of the Milky Way.
5) Adjust the skyglow data for increased airglow due to an increase in solar activity as we approach the next sunspot maximum

The processing of the SQM data toward each goal diverges at step 4, the handling of the effect of the Milky Way. For Goal #1, processing for Dark Sky Place certification, we exclude data samples acquired with the Milky Way overhead, which is consistent with DarkSky International advice to not include the Milky Way in any SQM readings. Also, for Goal #1, consistent with that advice, we include data from all seasons without adjustment, to characterize the annual night sky brightness at a site.

For Goal #2, long-term tracking, instead of discarding the Milk Way data, we choose to include it all. And further for Goal #2, in step 5 we adjust the data for estimated changes of airglow.

Goals #1 and #2

Processing Step 1 – Eliminate data influenced by the Sun, Moon and Clouds

Eliminating the effects of sunlight and moonlight is straightforward. To eliminate measurements affected by sunlight, we only consider data recorded after astronomical twilight (dusk) and before the start of astronomical twilight (dawn) – defined as the period during which the Sun is 18 degrees or more below the horizon. To eliminate measurements affected by moonlight, we only consider SQM data recorded when the Moon is 10 degrees or more below the horizon.

Clouds at night significantly affect the brightness of the sky recorded by the SQMs. Figure 4 shows details of SQM data from five sites recorded during the night of August 10-11, 2019, which was a particularly cloudy night across Central Oregon. The data show rapid variation at the 5-minute sampling interval due to changing cloud conditions overhead during that night. The rapid variation over time, caused by clouds is quite different from the smooth track of data acquired during clear nights, as shown in Figure 3.

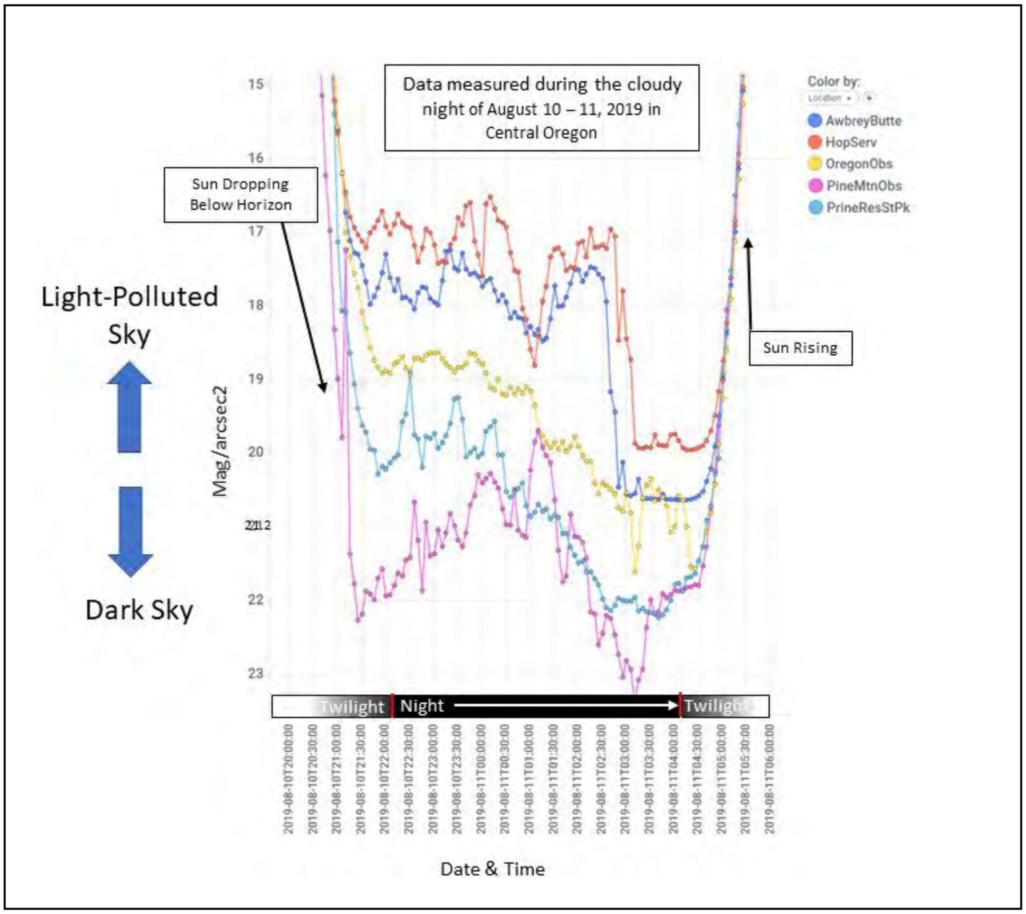


Figure 4. *SQM data recorded during a particularly cloudy night across Central Oregon. The data show rapid variation at the 5-minute sampling interval due to changing cloud conditions overhead during that night.*

To eliminate skyglow measurements taken during cloudy periods, we use an algorithm that measures the "jagginess" of the skyglow data over a 90-minute period. If the skyglow data are relatively smooth over a 90-minute period, we assume that clouds are not present, and we include the center point of that period as a clear sky measurement. This algorithm is based on one used by Grauer and others, 2019, but modified to employ the Residual Standard Error (RSE) as a measure of deviation from a linear fit. See Appendix B for details. We use an RSE cutoff of 20 to exclude cloudy, that is "jaggy", data. Points at the center of each 90-minute segment are excluded if the RSE for that segment is larger than 20, otherwise the point is considered to be measured during clear sky conditions. Note that in a previous report, Edition #4, we used an RSE cutoff of 50, but as explained in Appendix B, we now choose the more conservative cutoff of 20.

The cloud detection algorithm assumes that cloud cover is variable over time. Data acquired under constant cloud cover or in foggy conditions is not caught by the cloud algorithm. We eliminate those data by a different algorithm, described in Appendix B.

Note in Figure 4 that the clouds caused quite bright skyglow readings at the Awbrey Butte and Hopservatory sites, which are light-polluted – the artificial light from the ground reflects downward from the clouds. The inverse occurs at dark sky sites – note that clouds at the Pine Mountain site caused readings much greater than 22 mags/arcsecond^2 in the early morning hours, an unreasonably dark reading for a natural sky – caused by black-appearing clouds blocking the stars. See Appendix C for detailed data plots of this phenomenon and a discussion of the skyglow signature of a site.

Goals #1 and #2

Processing Step 2 - Adjust data for SQM hardware conditions –the weatherproof case and SQM aging

The SQM hardware resides inside a weatherproof case. The top of the case has a clear window that slightly darkens each measurement. Unihedron, the manufacturer, specifies that users should subtract 0.11 magnitudes per arc second squared from the data to account for the presence of this window. Accordingly, we do so.

Recent research (Puschnig and others, 2020) using SQMs from three different locations, documents that as the SQM device and weatherproof enclosure age, there is a darkening effect on measured data, in their case an average of about .04 mags/arcsecond^2 per year. This aging effect increases the skyglow measurements over time, making the sky seem slightly darker than reality. Other researchers (Alarcon and others, 2021) found no evidence of aging of a different photometer, the TESS instrument.

Unihedron (personal communication, 2022) notes that two issues can be involved: 1) development of a translucent film on the blue glass IR filter, which seems related to moisture and 2) yellowing of the plastic case of the semiconductor sensor over time.

To understand this phenomenon better, we obtained two new SQMs and installed them to run in parallel to two SQMs that had been running for several years. The results from our experiment suggest that a darkening effect is present, but a smaller one compared to the estimate from Puschnig and others. Our estimate is .019 mags/arcsecond^2 per year. Accordingly, we subtract values proportional to this assumed aging effect from our data, based on the progressive, serial exposure over time of measurements from each SQM in our network. See details in Appendix D.

Goals #1 and #2

Processing Step 3 - Eliminate out of bounds values

It is widely considered that the darkest clear night sky should not have any zenith brightness values greater than 22.0 mags/arcsecond^2. Other observations suggest that some night skies reach up to 22.1 or even 22.3 mags/arcsecond^2. At present, we apply a limit of 22.0 for the majority of our SQM sites and a limit of 22.1 for several of the darkest sky locations. See Appendix C for additional comments.

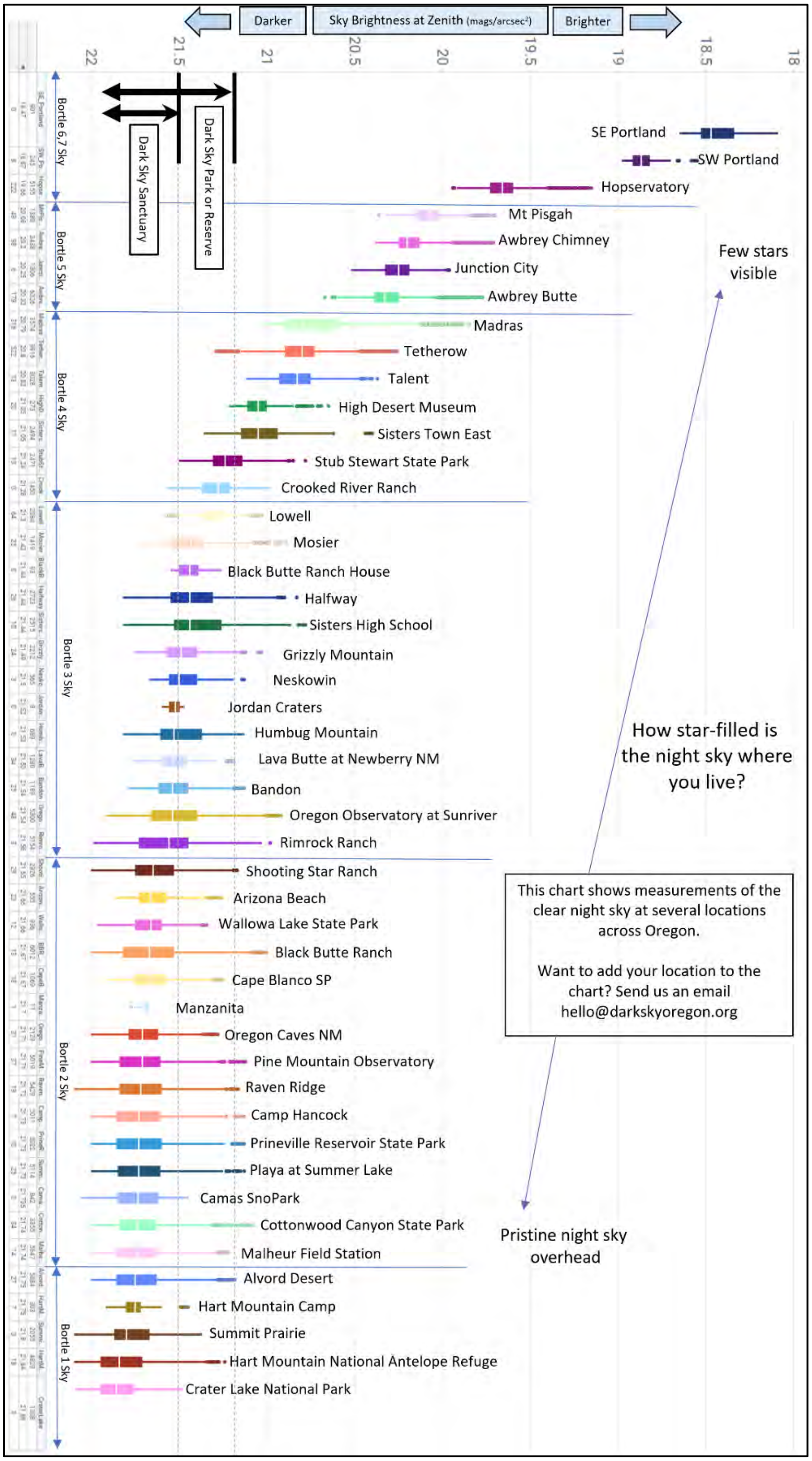
Goal #1

Processing Step 4 - Filter out measurements taken when the Milky Way is overhead

As noted above, when processing the SQM data for Dark Sky Place certification, we exclude data samples acquired with the Milky Way overhead, which is consistent with DarkSky Internatinal advice to not include the Milky Way in any SQM readings, to avoid biasing the data. Accordingly, we eliminate any data points acquired when the plane of the Milky Way is within 30 degrees of the zenith. We choose thirty degrees to accommodate the 20-degree FOV (10 degrees half width half maximum) of the SQM, plus 10 more degrees to take a conservative approach.

After Steps 1-4, the processing for Goal #1, for Dark Sky Place measurements, is complete. We have removed the effects of the sun, moon, clouds, weatherproof cover, SQM aging, out of bounds data and presence of the Milky Way. So, we can compare the brightness of the clear night skies at the current sites (Figure 5). Figure 5 lists the sites for which we had clear night data when the Milky Way was not overhead, as of the November 2023 deadline for this report.

The sites are organized in Figure 5 by the median value of the site's SQM data – the highest amount of light pollution on the top to the least on the bottom. The sites on the very bottom have essentially pristine night skies overhead. As we acquire additional data over time, the exact order of the sites may change.



Few stars visible

How star-filled is the night sky where you live?

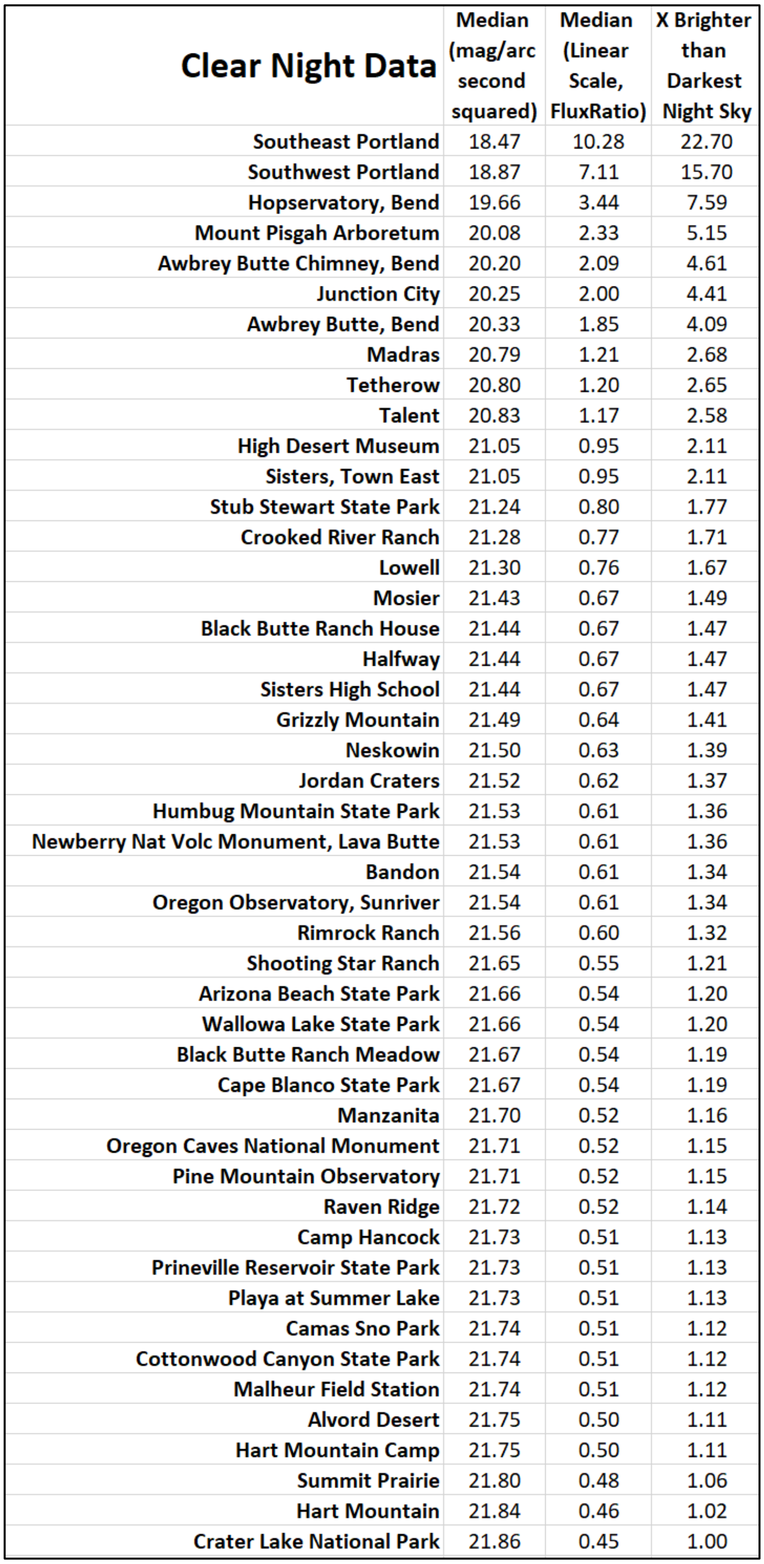
Pristine night sky overhead

This chart shows measurements of the clear night sky at several locations across Oregon.

Want to add your location to the chart? Send us an email hello@darkskyoregon.org

Figure 5. *Box plot showing the clear sky measurements of the sites as of the November 2023 deadline for this report. A couple sites are not yet on the plot because we don't yet have clear night data from them when the SQM was not looking at the Milky Way. DarkSky International's cutoffs for Dark Sky Places are shown in the upper left. Many of our measurement sites qualify for dark sky place certification. The vertical black line in each box marks the median value. The horizontal size of the box marks the central 50% of data. The Bortle Sky classification is shown on the left side. Table 1 provides the summary statistics at each site.*

Table 1 summarizes the average brightness of the night sky in Figure 5 for each site in the logarithmic mags/arcsecond^2 scale. The “X Brighter” column in Table 1 on the far right shows how much brighter, on a linear scale, each site is compared to Crater Lake National Park, the darkest night sky site in our data set to date. The clear night skies in and near the cities of central Oregon are 3x to 7x brighter, that is, 3x to 7x more light-polluted, than the night skies at Crater Lake. Clear night skies at the two sites in the city of Portland, at the top of Table 1, are about 20x brighter than the clear night skies at Crater Lake.



Clear Night Data	Median (mag/arc second squared)	Median (Linear Scale, FluxRatio)	X Brighter than Darkest Night Sky
Southeast Portland	18.47	10.28	22.70
Southwest Portland	18.87	7.11	15.70
Hopservatory, Bend	19.66	3.44	7.59
Mount Pisgah Arboretum	20.08	2.33	5.15
Awbrey Butte Chimney, Bend	20.20	2.09	4.61
Junction City	20.25	2.00	4.41
Awbrey Butte, Bend	20.33	1.85	4.09
Madras	20.79	1.21	2.68
Tetherow	20.80	1.20	2.65
Talent	20.83	1.17	2.58
High Desert Museum	21.05	0.95	2.11
Sisters, Town East	21.05	0.95	2.11
Stub Stewart State Park	21.24	0.80	1.77
Crooked River Ranch	21.28	0.77	1.71
Lowell	21.30	0.76	1.67
Mosier	21.43	0.67	1.49
Black Butte Ranch House	21.44	0.67	1.47
Halfway	21.44	0.67	1.47
Sisters High School	21.44	0.67	1.47
Grizzly Mountain	21.49	0.64	1.41
Neskowin	21.50	0.63	1.39
Jordan Craters	21.52	0.62	1.37
Humbug Mountain State Park	21.53	0.61	1.36
Newberry Nat Volc Monument, Lava Butte	21.53	0.61	1.36
Bandon	21.54	0.61	1.34
Oregon Observatory, Sunriver	21.54	0.61	1.34
Rimrock Ranch	21.56	0.60	1.32
Shooting Star Ranch	21.65	0.55	1.21
Arizona Beach State Park	21.66	0.54	1.20
Wallowa Lake State Park	21.66	0.54	1.20
Black Butte Ranch Meadow	21.67	0.54	1.19
Cape Blanco State Park	21.67	0.54	1.19
Manzanita	21.70	0.52	1.16
Oregon Caves National Monument	21.71	0.52	1.15
Pine Mountain Observatory	21.71	0.52	1.15
Raven Ridge	21.72	0.52	1.14
Camp Hancock	21.73	0.51	1.13
Prineville Reservoir State Park	21.73	0.51	1.13
Playa at Summer Lake	21.73	0.51	1.13
Camas Sno Park	21.74	0.51	1.12
Cottonwood Canyon State Park	21.74	0.51	1.12
Malheur Field Station	21.74	0.51	1.12
Alvord Desert	21.75	0.50	1.11
Hart Mountain Camp	21.75	0.50	1.11
Summit Prairie	21.80	0.48	1.06
Hart Mountain	21.84	0.46	1.02
Crater Lake National Park	21.86	0.45	1.00

Table 1. *Summary of SQM* ***clear night data*** *at each location. The median values in the first data column are in the logarithmic units of* ***mags/arcsecond***^{2}*. The second data column lists the median values after conversion to a linear brightness scale. The "X Brighter" column shows how much brighter is the clear night sky at each site on the linear scale compared to the current darkest site – the SQM at Crater Lake National Park. The clear night skies in Portland, OR are about 20x brighter than at Crater Lake National Park.*

Skyglow from Cloudy Nights – the Second Part of the Signature

The previous section summarized the clear night data from each measurement site. We also want to characterize each site's measurements during cloudy conditions. We achieve that by selecting the "jaggy" data – namely points that have a RSE value greater than the cutoff of 20.

Table 2 summarizes the statistics for these measurements taken during cloudy conditions. The "X Brighter" column in Table 2 shows that under clouds, the night sky in Portland, Oregon is up to 300x brighter than the sky under cloudy conditions at the darkest sky locations. Clouds near cities reflect light pollution back down to the surface environment causing very bright night sky readings. By contrast, clouds at a dark sky site like Crater Lake National Park or Hart Mountain appear black because there is no artificial light pollution coming from the ground to light them up. Additionally, the clouds block out starlight, so pristine night sky sites are particularly dark when the sky is overcast.

We can consider the skyglow at the dark sky sites to be the natural case, and the skyglow over cities – those sites near the top of Table 2 - to be quite un-natural. The impact on the wild ecosystem of light pollution in cloudy conditions within and near cities is likely significant.

Cloudy Night Data	**Median (mag/arc second squared)**	**Median (Linear Scale, FluxRatio)**	**X Brighter than Darkest Night Sky**
Southeast Portland	16.41	68.55	316.23
Southwest Portland	16.95	41.69	192.31
Hopservatory, Bend	18.77	7.80	35.97
Mount Pisgah Arboretum	18.93	6.73	31.05
Junction City	18.98	6.43	29.65
Awbrey Butte Chimney, Bend	19.18	5.35	24.66
Awbrey Butte, Bend	19.38	4.45	20.51
Tetherow	19.77	3.10	14.32
Madras	19.88	2.81	12.94
Talent	20.06	2.38	10.96
Lowell	20.42	1.71	7.87
Sisters, Town East	20.5	1.58	7.31
High Desert Museum	20.61	1.43	6.61
Oregon Observatory, Sunriver	20.86	1.14	5.25
Halfway	20.89	1.11	5.11
Crooked River Ranch	20.94	1.06	4.88
Sisters High School	20.97	1.03	4.74
Bandon	21.06	0.95	4.37
Mosier	21.12	0.90	4.13
Manzanita	21.22	0.82	3.77
Stub Stewart State Park	21.25	0.79	3.66
Neskowin	21.32	0.74	3.44
Grizzly Mountain	21.36	0.72	3.31
Black Butte Ranch House	21.37	0.71	3.28
Newberry Nat Volc Monument, Lava Butte	21.37	0.71	3.28
Rimrock Ranch	21.53	0.61	2.83
Black Butte Ranch Meadow	21.58	0.59	2.70
Prineville Reservoir State Park	21.67	0.54	2.49
Arizona Beach State Park	21.68	0.53	2.47
Shooting Star Ranch	21.71	0.52	2.40
Camas Sno Park	21.76	0.50	2.29
Hart Mountain Camp	21.77	0.49	2.27
Wallowa Lake State Park	21.77	0.49	2.27
Summit Prairie	21.79	0.48	2.23
Humbug Mountain State Park	21.8	0.48	2.21
Cape Blanco State Park	21.83	0.47	2.15
Oregon Caves National Monument	21.83	0.47	2.15
Cottonwood Canyon State Park	21.84	0.46	2.13
Playa at Summer Lake	21.89	0.44	2.03
Malheur Field Station	21.93	0.42	1.96
Raven Ridge	21.93	0.42	1.96
Alvord Desert	21.95	0.42	1.92
Pine Mountain Observatory	21.95	0.42	1.92
Camp Hancock	21.96	0.41	1.91
Hart Mountain	22	0.40	1.84
Crater Lake National Park	22.66	0.22	1.00
Jordan Craters	23.355	0.11	0.53

Table 2. *Summary of SQM* ***cloudy night data*** *at each location. The median values in the first data column are in the logarithmic units of* ***mags/arcsecond***^{2}*. These data have been filtered to remove data acquired when the Milk Way is within 30 degrees of zenith. Values higher than 22.0 mags/arc second squared are included because they record the fact that clouds will block the stars and are representative of cloudy conditions. The third column lists the median values after conversion to a linear brightness scale. The "X Brighter" column shows how much brighter on the linear scale is the cloudy night sky at each site compared to the SQM at Crater Lake National Park. The cloudy night skies in Portland, Oregon are up to 300x brighter than cloudy nights at Crater Lake National Park. Note that the Jordon Craters site at the bottom of the table currently shows a very dark cloudy median value – we anticipate that this is due to the limited number of data points at present from that site, most of which were acquired under cloudy conditions.*

Goal #2 – Determine long term change of light pollution

Processing Step 4 - Keep all of the data, irrespective of the position of the Milky Way

When the Milky Way is overhead, the SQM will record a brighter night sky. For Goal #2, instead of eliminating those measurements as we did for Goal #1, we keep those data. We also convert the SQM data from the logarithmic scale (mags/arc second squared) to a linear scale which is needed to properly track change over time.

Astronomers employ a useful method to convert logarithmic night sky brightness data to a linear scale. A logarithmic zero point is chosen, for example at 21.0 magnitudes per arc second squared, then the equation used to define the magnitude scale is inverted, which provides data on a linear scale. The equation in Excel format is the following, in which "SQM" is a measurement value in magnitudes per arc second squared.

Vlin = POWER(10,(SQM – 21.0) / -2.5)

All of the SQM measurements are processed by this equation to generate a data set with linear properties.

In previous editions of this report, we adjusted the SQM data for three attributes which cause the data to vary over time: the position of the Milky Way (galactic latitude and longitude) and time of night. Adjustments for these attributes increase the goodness of fit of the data over time by about 15% R-squared, the majority of which is due to galactic latitude. However, the long-term trends don't change very much by applying those adjustments, especially for sites with two years or more data. Accordingly, we simplify the analyses by eliminating those adjustments.

Goal #2

Processing Step 5 – Adjust SQM data for increase of airglow due to increase of solar flux

Another factor to consider in zenith skyglow trends over long periods is variations of airglow, the light emitted from the atmosphere itself due to the impact of space weather on Earth (Grauer and others, 2019; Grauer & Grauer, 2021). Airglow is known to vary on a wide range of time scales, from rapid variation in minutes across one night, to strong, years-long changes correlated to the 11-year solar sunspot cycle.

There are several known causes of airglow variation, including (1) the solar flux input to the earth's atmosphere which arrives in about 7 minutes from the sun at the speed of light, (2) impact of the solar wind's magnetic field, which arrives from the sun in about 4.5 days and (3) its interaction with the earth's magnetic field. In the following, we adjust our skyglow data for variations in (2), based on measurements of the solar flux, which can play a significant role in estimates of skyglow change per year.

The sun is currently rising out of a solar sunspot minimum, toward a predicted sunspot maximum in July 2025. So, space weather may cause our SQM data to read brighter since our SQM project began in mid-2019, by increased airglow, independently of any changes in light pollution from the ground.

Accordingly, we have estimated the increase of airglow since the beginning of our SQM project, and adjusted the SQM data of our long-term sites. We obtain the estimate of night sky brightness due to airglow by assuming that the zenith night sky brightness at two dark sky sites have not changed due to artificial lighting over the duration of the SQM surveys. The process of adjustment for airglow is described in Appendix E.

Changes of Skyglow over Time

After processing the SQM data for Goal #2, (namely through weatherproof cover, SQM age and solar flux/airglow), we plot the adjusted data over the time since we began recording data. Figure 6 shows the adjusted clear night sky data for the 27 sites for which we have at least two years of data, plotted over time. The solid line across each data subset in Figure 6 is a linear regression fit to the sky brightness recorded over time.

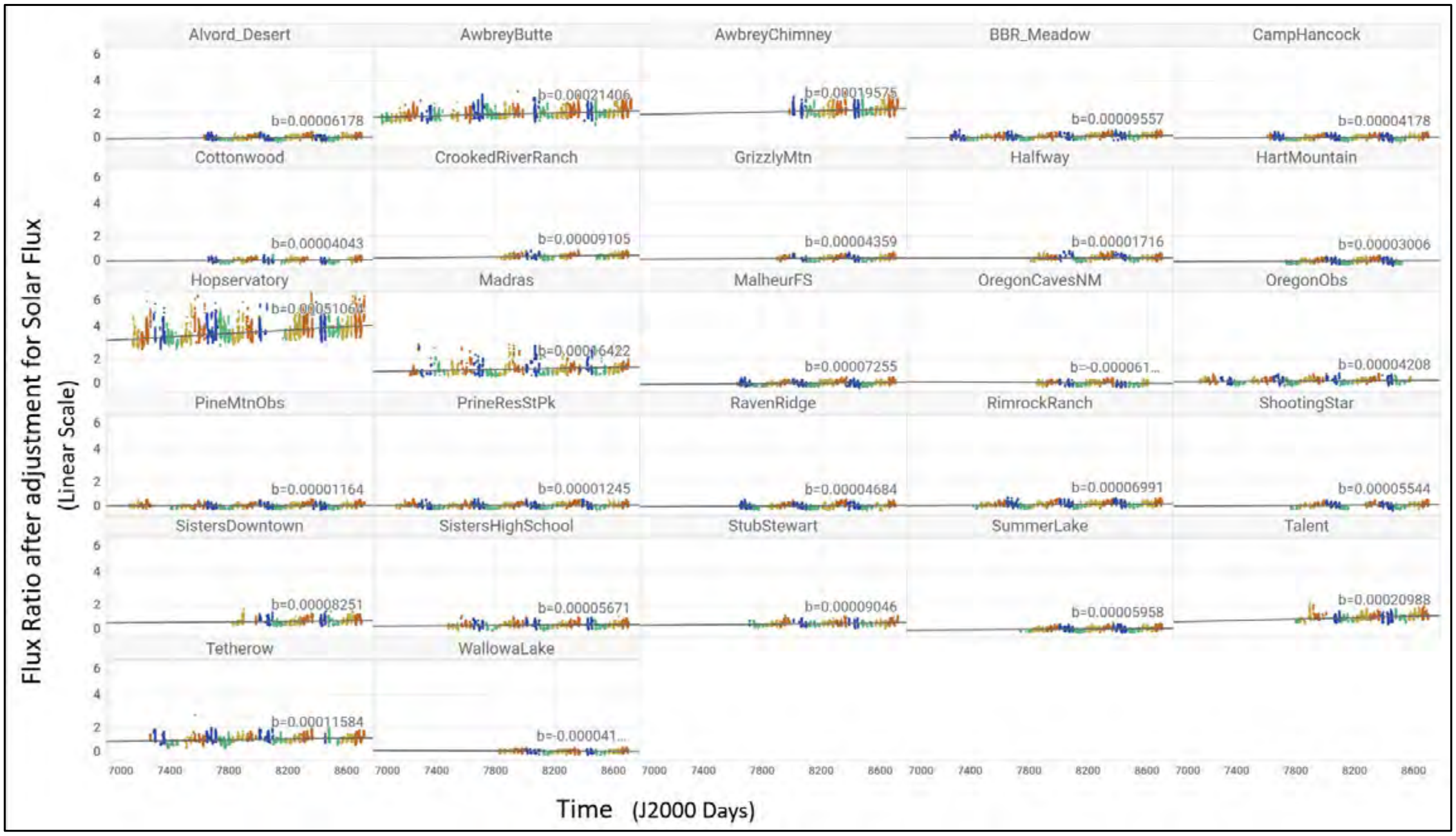


Figure 6. The clear night sky data for 27 long-term sites, after adjustment for solar flux. Each cluster of vertically-smeared points were acquired during a new moon period. The data points are colored by season of the year. The black line in each diagram is a linear fit to the data, with slope (b) posted. Also see Figure 7.

Table 3 summarizes the long-term change statistics for these 27 sites. It is traditional to quote a percentage change per year, but percentages are comparable to each other only when the starting point is the same. In our case, the starting points all differ – namely we have a range of night sky brightness – from very dark to very bright.

A better statistic to assess change is the slope of the regression line in the fit of change over time. And, to quote it in comparison to one of the sites where change is slow. So, the first data column of Table 3 lists the slope of the respective regression lines for each site, multiplied by 10,000 to make the numbers more legible. The second data column compares the slope of each site to the Prineville Reservoir State Park site, which is a certified Dark Sky Park, and where we don't expect much change in sky brightness. The rate of change at that State Park is given the value of 1.00 and the other sites vary by comparison. The Hopservatory site in Bend, for example, in increasing in brightness at a rate of 28 times faster than at the State Park.

The third data column in Table 3 lists the annual percentage change for each site. Note that the percentage change at Prineville Reservoir State Park is estimated to be 1.1% per year, while the percentage change at the Hopservatory is about 6% per year. So, sites with bright night skies (Hopservatory) appear to have less of an issue when the percentage statistic is used. In reality the rate of change is dramatically larger at the Hopservatory, compared to the State Park site.

Location	Slope of Regression Line x 10000	Rate of Change vs PRSP	Annual Pct Change
Oregon Caves National Monument	-0.50	-2.74	-3.0
Wallowa Lake State Park	-0.33	-1.82	-2.0
Pine Mountain Observatory	0.18	0.98	1.1
Prineville Reservoir State Park	0.18	1.00	1.1
Halfway	0.25	1.38	1.3
Hart Mountain	0.42	2.27	2.9
Oregon Observatory, Sunriver	0.48	2.64	2.6
Cottonwood Canyon State Park	0.49	2.65	3.2
Camp Hancock	0.50	2.74	3.4
Grizzly Mountain	0.52	2.85	2.8
Raven Ridge	0.55	3.02	3.7
Shooting Star Ranch	0.64	3.50	3.9
Sisters High School	0.65	3.52	3.1
Playa at Summer Lake	0.69	3.75	4.7
Alvord Desert	0.70	3.83	4.8
Rimrock Ranch	0.78	4.26	4.7
Malheur Field Station	0.81	4.42	5.6
Sisters, Town East	0.92	5.02	3.4
Stub Stewart State Park	0.99	5.42	4.3
Crooked River Ranch	0.99	5.42	4.6
Black Butte Ranch Meadow	1.02	5.58	6.7
Tetherow	1.22	6.66	3.7
Madras	1.71	9.31	4.8
Awbrey Butte Chimney, Bend	2.05	11.16	3.5
Talent	2.19	11.93	6.9
Awbrey Butte, Bend	2.20	11.99	4.5
Hopservatory, Bend	5.17	28.18	5.8

Table 3. Statistics of change for the 27 long-term SQM sites. The rate of change (second data column) is a preferred way to characterize change over time. The annual percentage change is biased by the starting point of the calculation. See text for additional comments.

The large rate-of-change in the light-polluted sites in central Oregon (five of the six sites at the bottom of Table 3) seems due to the increase in population of that area over the past few years along with ineffective enforcement of the existing lighting ordinances.

In summary, we recognize various sky brightness trends in our data. Going forward, we continue to acquire additional data and will follow up at several sites to better understand the origin of the trends.

At the darker sites, changes of skyglow will be more evident near the horizon. This calls for an additional measuring system, such as a calibrated all-sky camera. This could be either a tripod-mounted system used at key sites during cloud-free, new moon conditions or an all-weather camera, always operating, acquiring images and periodically calibrated to further understand seasonal patterns and other issues that may become evident.

Milky Way Visibility

We have calculated an index of Milky Way Visibility from our extensive SQM data. The index is a measure of how bright the Milky Way is at each SQM site by comparison to the brightness of the remainder of the night sky at that site. We anticipate that this index will be great interest to nightscape photographers, visual observers, and deep space astrophotographers.

The index is a comparison of the night sky brightness at each site -- of measurements obtained when the SQM is looking into the Milky Way versus measurements taken when the Milky Way is not in the SQM field of view. Recall that the SQMs are pointed to zenith and have a field of view of about 20 degrees.

For the case of the SQM looking into the Milky Way, we include all clear night measurements across the years, when the central arc of the Milky Way is within plus or minus 30 degrees of the zenith. For the case of the SQM not looking at the Milky Way, we include all clear night measurements when the central arc of the Milky Way is more than 30 degrees away from the zenith.

We calculate this index both from the difference of logarithmic magnitudes/arc second squared data, and from a ratio of linear scale SQM flux data. Both are calculated as different observers may prefer one over the other. The indices in each case are consistent, plot against each other in linear fashion (not shown) and each provides useful information. Table 4 shows the data.

The first data column in Table 4 lists the difference of the median values at each site, for the night sky brightness when the Milky Way is seen by the SQM versus not. The units are magnitudes per arc second squared.

The second data column in Table 4 shows the same information but as a unitless ratio of linear flux data measured by the SQM. It can be interpreted by noting that, for example, the Milky Way at the Hart Mountain and Crater Lake sites is 1.3x brighter than the surrounding night sky. And at the two Portland sites, the Milky Way does not stand out in contrast to the surrounding night sky at all.

	Difference Index (Magnitudes/arc second squared)	Ratio Index (unitless)
Southeast Portland	-0.060	0.946
Southwest Portland	0.020	1.019
Mount Pisgah Arboretum	0.030	1.028
Hopservatory, Bend	0.060	1.057
Junction City	0.060	1.057
Manzanita	0.080	1.076
Awbrey Butte Chimney, Bend	0.090	1.086
Awbrey Butte, Bend	0.090	1.086
High Desert Museum	0.130	1.127
Crooked River Ranch	0.140	1.138
Sisters, Town East	0.140	1.138
Talent	0.150	1.148
Humbug Mtn State Park	0.160	1.159
Wallowa Lake State Park	0.160	1.159
Halfway	0.160	1.159
Tetherow	0.160	1.159
Lowell	0.170	1.169
Madras	0.180	1.180
Mosier	0.180	1.180
Arizona Beach State Park	0.180	1.180
Stub Stewart State Park	0.190	1.191
Neskowin	0.190	1.191
Grizzly Mountain	0.210	1.213
Rimrock Ranch	0.220	1.225
Bandon	0.220	1.225
Cape Blanco State Park	0.220	1.225
Newberry Nat Volc Mon, Lava Butte	0.230	1.236
Oregon Caves National Monument	0.240	1.247
Pine Mountain Observatory	0.250	1.259
Playa at Summer Lake	0.250	1.259
Oregon Observatory, Sunriver	0.250	1.259
Shooting Star Ranch	0.260	1.271
Camp Hancock	0.260	1.271
Sisters High School	0.260	1.271
Hart Mountain Camp	0.260	1.271
Camas Sno Park	0.265	1.276
Cottonwood Canyon State Park	0.270	1.282
Malheur Field Station	0.270	1.282
Raven Ridge	0.270	1.282
Black Butte Ranch Meadow	0.280	1.294
Alvord Desert	0.280	1.294
Summit Prairie	0.280	1.294
Prineville Reservoir State Park	0.290	1.306
Crater Lake National Park	0.320	1.343
Hart Mountain	0.330	1.355

Table 4. Milky Way visibility at the various SQM sites. The Milky Way is most visible at the sites near the bottom of the table, and is mostly not visible for sites at the top of the table. The data columns are independently colored, from red at the top to green at the bottom. The consistent coloring of the two columns is a measure that the two indices provide the same information. See text for explanation.

Figures 8 and 9 show plots of the Milky Way visibility data from Table 3 versus the median night sky brightness at each site. Figure 8 shows the Difference Index on the horizontal scale. Figure 9 shows the Ratio Index on the horizontal scale. The plots show that as we would expect, the darker sky sites, those lower on the Y-axis, express increased visibility of the Milky Way. We anticipate that several sites will change position going forward, as additional data, across all seasons becomes available from them all.

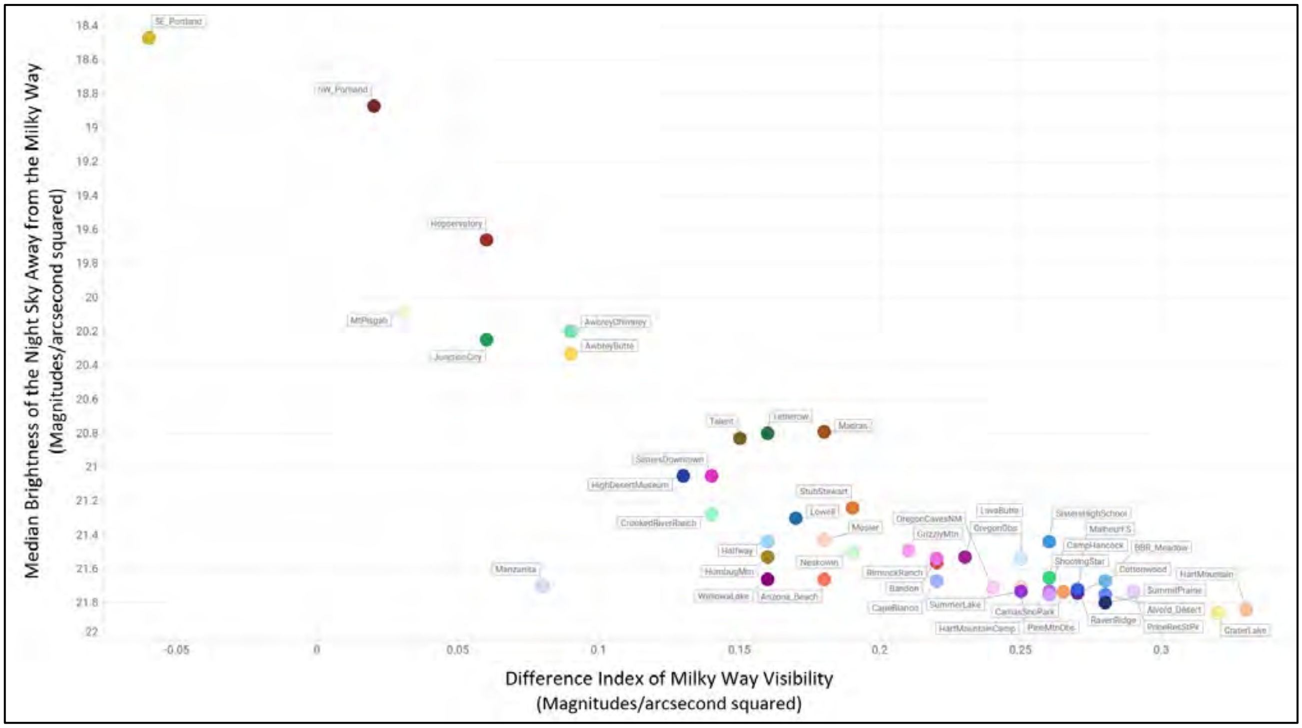


Figure 8. Difference Index of Milky Way Visibility on the horizontal axis versus median brightness of the night sky away from the Milky Way on the vertical axis. The Milky Way is most visible and with greatest contrast at the sites in the lower right of the diagram.

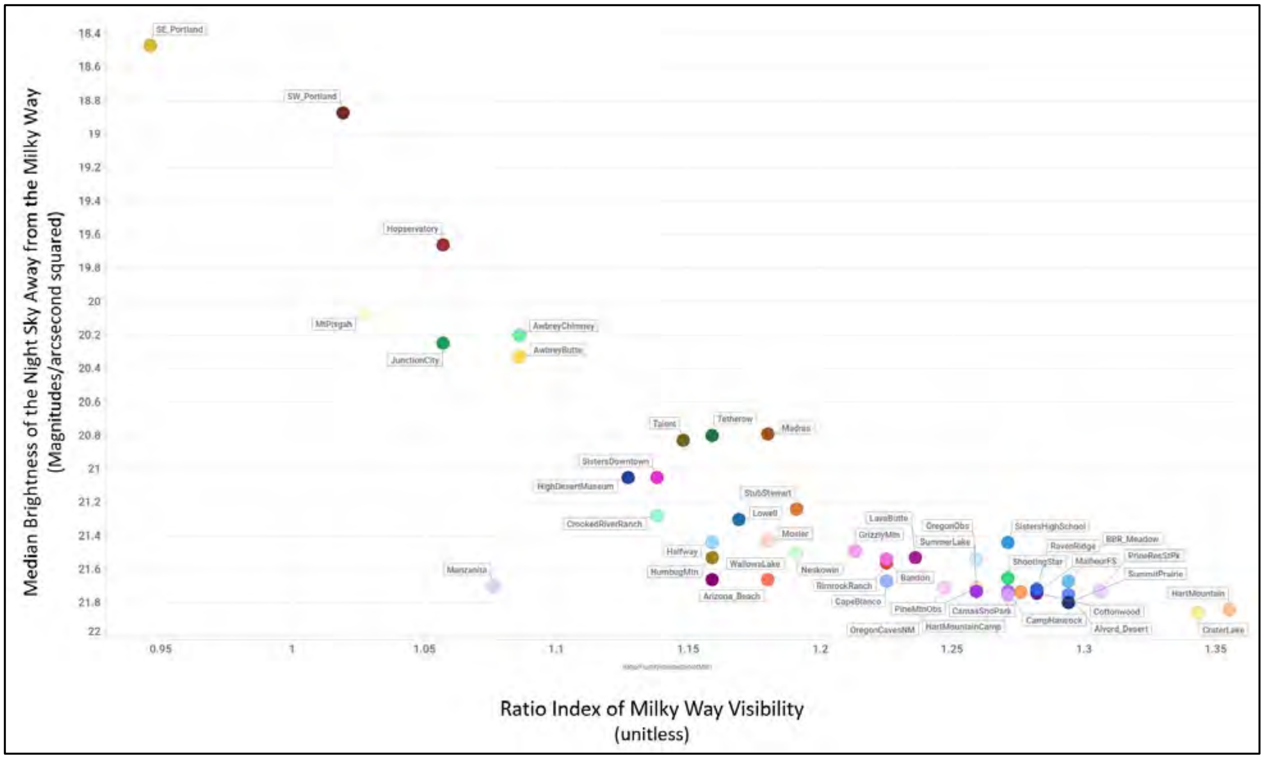


Figure 9. Ratio Index of Milky Way Visibility on the horizontal axis versus median brightness of the night sky away from the Milky Way on the vertical axis. The Milky Way is most visible and with greatest contrast at the sites in the lower right of the diagram.

Acknowledgements
DarkSky Oregon acknowledges and thanks the representatives at the public and private SQM sites for their continued support on this project -- the Hopservatory, Tetherow, Madras, the Oregon Observatory at Sunriver, Black Butte Ranch, Prineville Reservoir State Park, the Pine Mountain Observatory, Rimrock Ranch, Sisters High School, Astronomy Club of City of Sisters, Crooked River Ranch, Grizzly Mountain, Camp Hancock, the Malheur Field Station, Raven Ridge, Southern Oregon Travel, Oregon Outback Dark Sky Network, Stub Stewart State Park, Shooting Star Ranch, Summer Lake, Summit Prairie, Alvord Desert, Hart Mountain National Antelope Refuge, Halfway, Manzanita, Jordon Craters, Camas Sno Park, Hart Mountain Camp, Neskowin, Cottonwood Canyon State Park, Wallowa Lake State Park, Oregon Caves National Monument, Bandon, Mt Pisgah Arboretum, Lowell, Junction City, Southeast and Southwest Portland, Crater Lake National Park, Cape Blanco District of Oregon State Parks, Newberry National Volcanic Monument, City of Antelope and Eugene Downtown.

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Appendix A – Time duration of data from each SQM site

Figure A1 show the data coverage over time of each SQM site as of this Edition (#8) of the report. The chart is color-coded by the season of the year. Data gaps are caused by battery failure, structural support failure of the SQM mounting, or adverse weather conditions that prevented timely access. There are 27 sites with at least 2 years of data coverage. The long-range trend for those 27 sites is analyzed elsewhere in this report.

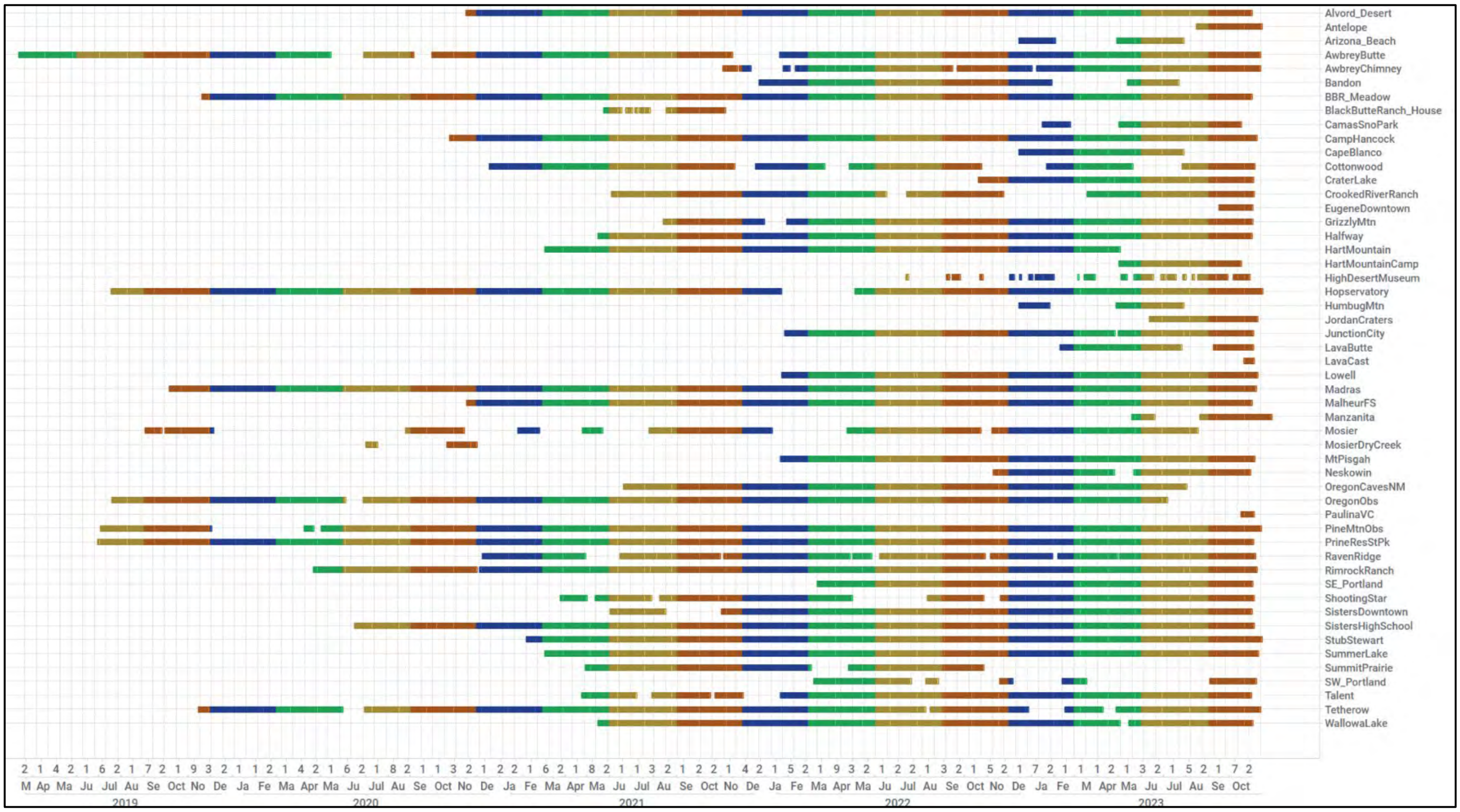


Figure A1. Time range of data available from the 52 SQMs as of the November 2023 deadline for this report. The plot is colored by seasons of the year.

Appendix B - Cloud Removal Algorithm

To eliminate skyglow measurements taken during cloudy periods, we use an algorithm that measures the “jagginess” of the skyglow data over a 90-minute period. If the skyglow data are relatively smooth over a 90-minute period, we assume that clouds are not present, and we include the center point of that period as a clear sky measurement. Figure B1 shows a diagrammatic explanation. Figure B2 shows data examples.

This algorithm is based on one used by Grauer and others, 2019, but modified to employ the Residual Standard Error (RSE) as a measure of deviation from a linear fit. This algorithm is now implemented in Unihedron’s UDM software, under the processing option “Tools/.dat to Sun-Moon-MW-Clouds.”

We use a RSE cutoff of 20 to exclude cloudy, that is “jaggy”, data. Points at the center of each 90-minute segment are excluded if the RSE for that segment is larger than 20, otherwise the point is considered to be measured during clear sky conditions.

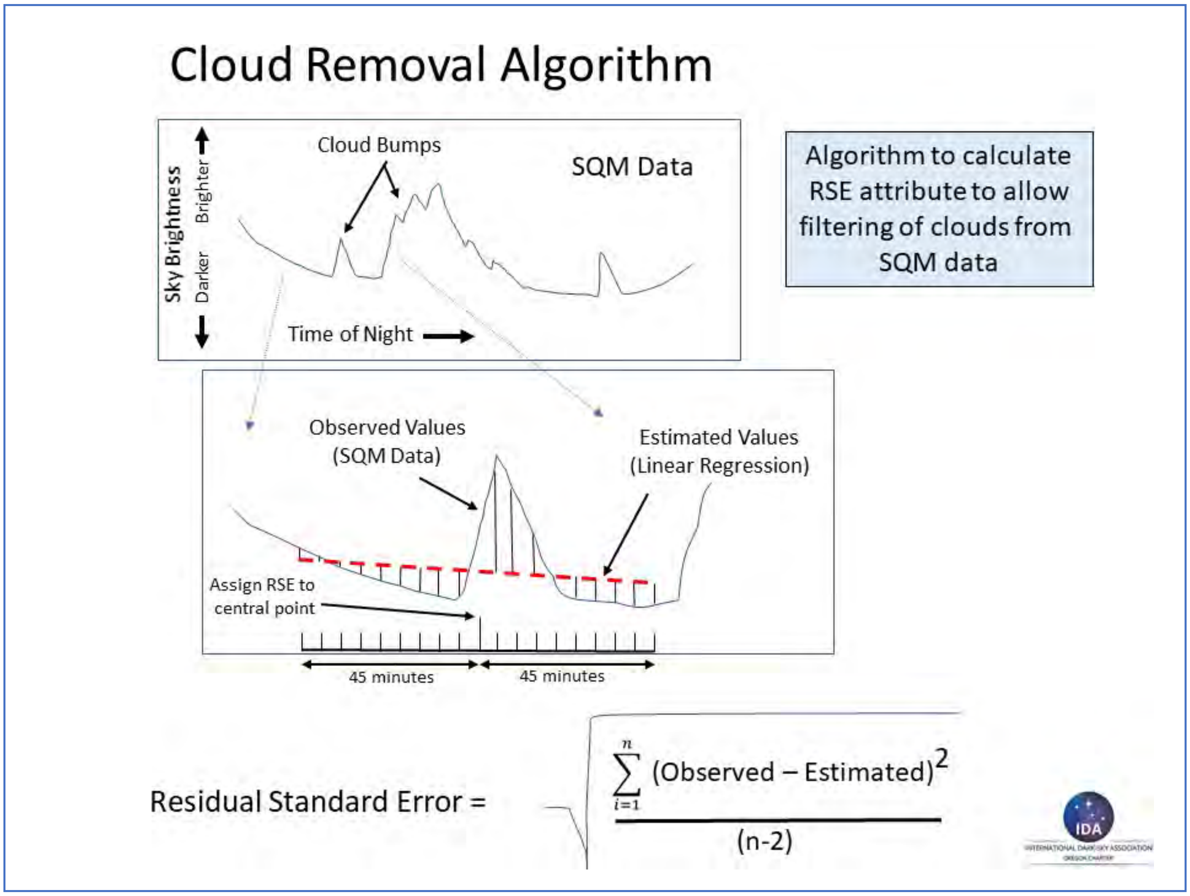


Figure B1. Diagrammatic explanation of the calculation of residual standard error which is used as the statistic to gauge the presence of clouds at each data point. We fit a linear regression to a sliding 90-minute interval of SQM data and assign the residual standard error to the center point of the time interval.

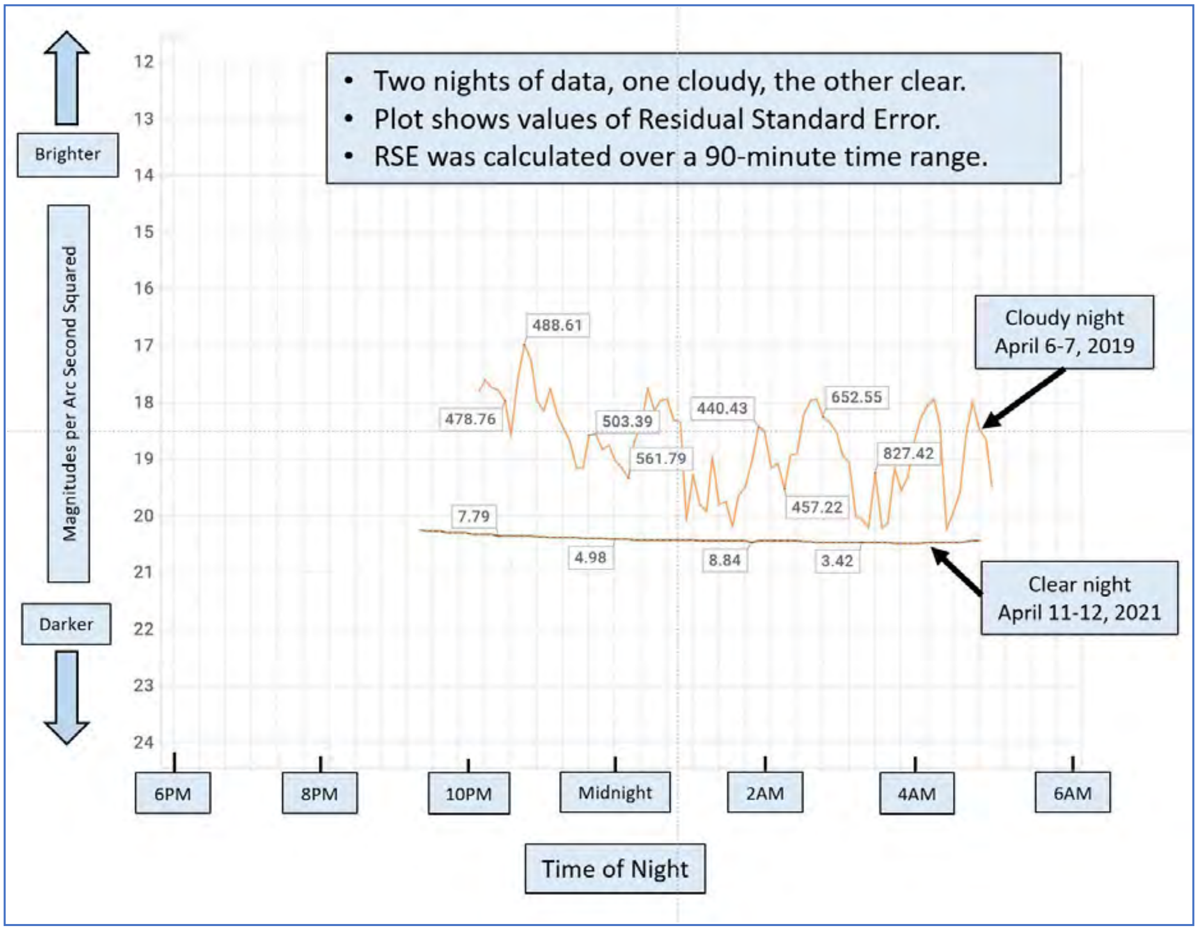


Figure B2. Data from two different nights, one cloudy, the other clear. The residual standard error values are shown at several point along the profiles. The clear night data has much smaller RSE values compared to data acquired during the cloudy night.

Filtering out cloudy data samples requires a choice of a cutoff RSE value. Previously we used a cutoff value of 50, but after studying density plots of RSE data (Figure B3), we chose a more conservative RSE value of 20. Figure B3 shows that a cluster of data points lies below the RSE value of 20. We take this as a natural clustering of cloud-free data, and accordingly use the RSE value of 20 to separate clear from cloudy data samples.

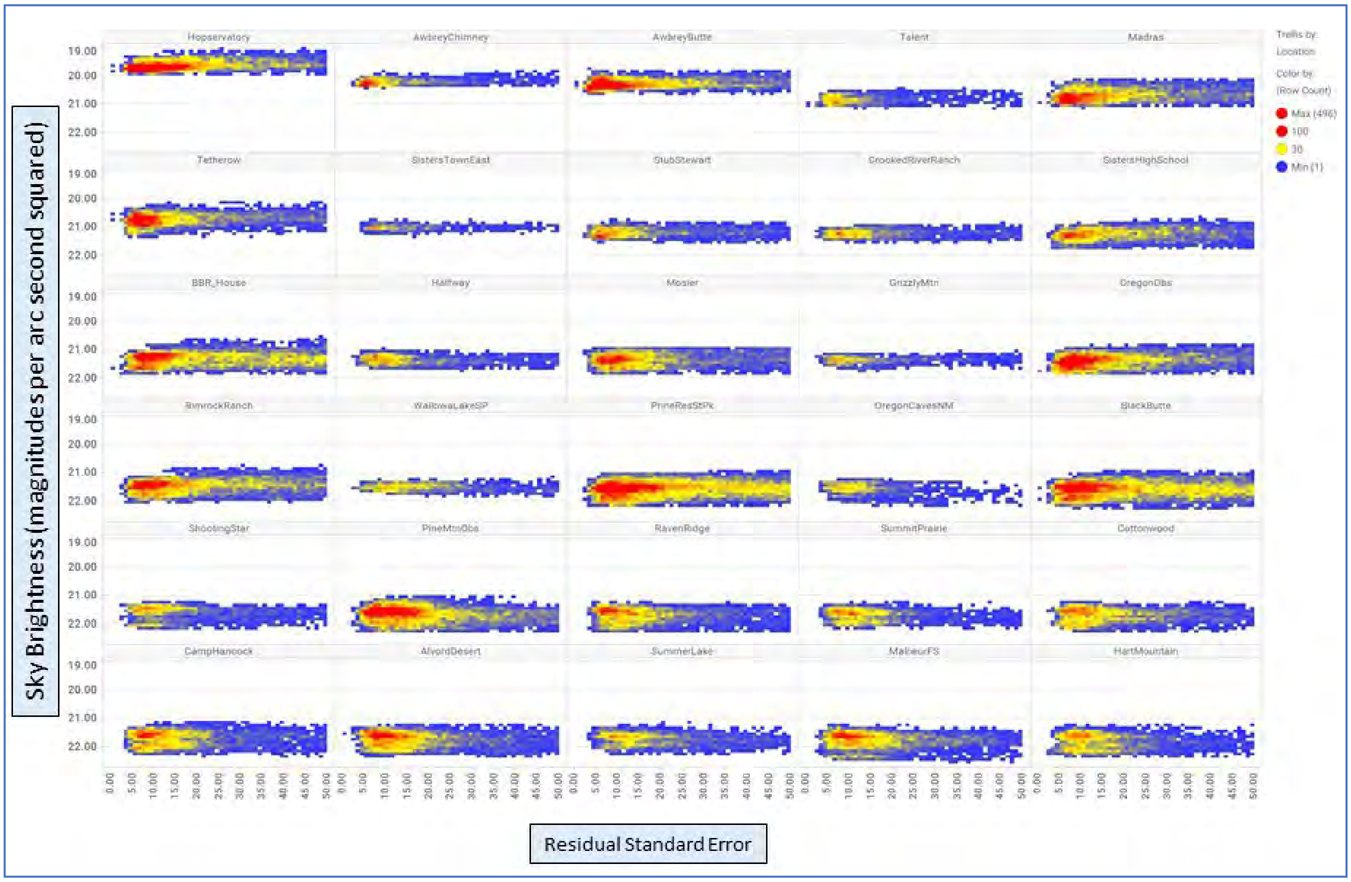


Figure B3. Density plot of residual standard error values versus sky brightness for all 30 SQM sites as of Edition #5 of this report. All of the sites show a cluster of values at the short end of the RSE scale. We choose a cutoff value of 20 going forward, to include those clustered values as clear sky data points.

The cloud removal algorithm effectively filters out SQM measurements acquired when cloud conditions vary during the 90-minute time span. However, it fails to remove cloudy data from periods of uniform overcast or fog – see Appendix C, Figure C4 for examples. In previous editions of this report, we manually deleted those sparse points outside the high-density data zone at each site. In this Edition #7 of the report series, we employ an automatic spatial filter to remove those points.

The spatial filter operates in the density plot domain as in Figure C4. Figure B4 shows an enlarged segment of the density plot domain. The Y-axis of the domain is magnitudes per arc second squared, binned by .05 magnitudes per arc second squared. The X-axis of the domain is time-since-1500-hours, binned by 5 minutes of time. The algorithm (Figure B4) uses an empirically-derived spatial operator, 7 bins tall by 3 bins wide. The operator is taller than wide because the patterns of interest tend to be horizontal in the density plot domain.

At each point of the density plot grid (Figure B4), the algorithm sums the number of measurements under the operator and applies the sum to the central point. If the sum is smaller than a cutoff value, then the central point is considered sparse and is eliminated from consideration. We use a cutoff of 25 for most of the sites, but iteratively customize the cutoff to smaller values for sites with fewer data points to date.

This algorithm removes sparse points outside of the high-density region of data. We assume that constant clouds and fog will cause measurements to be outside the high-density region of data at each site. The possibility exists of such data overlapping the high-density data, in which case we do not eliminate it. See additional comments and compare Figures C4 and C5 in Appendix C.

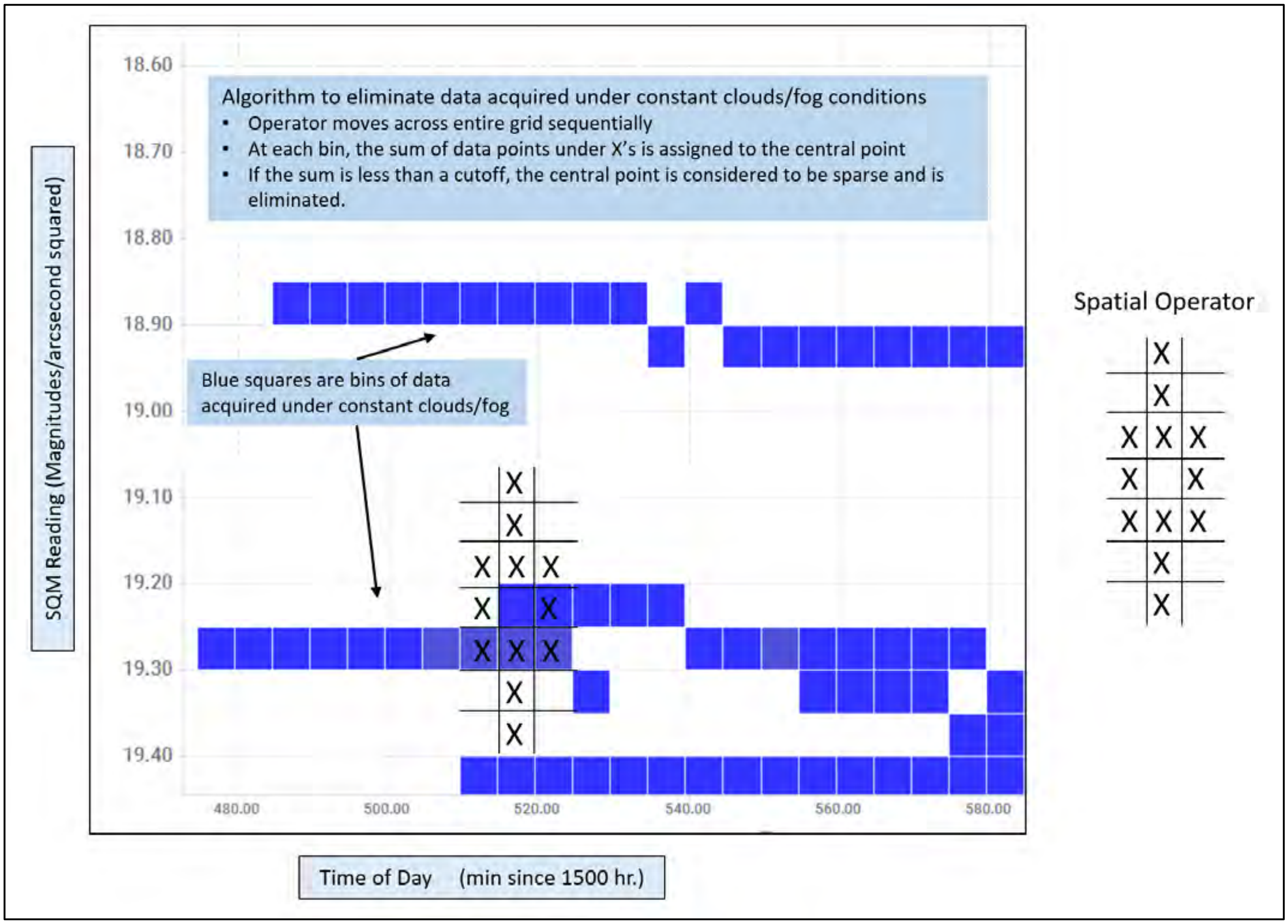


Figure B4. Algorithm to eliminate data acquired under constant clouds/fog conditions. The operator moves across the entire grid sequentially. At each bin of the grid, the sum of data points under the X's is assigned to the central point. If the sum is less than a cutoff, the central point is considered to be sparse and is eliminated. See Appendix C, Figures C4 and C5, for the results of applying this filter.

Appendix C - Skyglow Signature of a Site

Skyglow data acquired over months and years provides a cumulative signature, which is characteristic of the amount of light pollution at each measurement site. We summarize two main features of that signature: (1) the brightness of the clear night sky and (2) the brightness of the night sky during cloudy conditions.

Measurements of the darkness of the **clear night sky** are useful to satisfy Dark Sky Place criteria and for comparison between sites without the complication of variable cloud cover. The darkness of the night sky **during cloudy conditions** provides an enhanced measure of the environmental impact of light pollution. At light polluted sites, the clouds are lit up from below and cast much more light downward into the environment, compared to sites without light pollution -- where clouds overhead appear black and compound the natural darkness.

Figure C1 shows the SQM measurements acquired at the Awbrey Butte neighborhood of the City of Bend, from July 2019 to September 2020. The vertical axis is the SQM brightness reading. The horizontal axis is local time of the night, in minutes since 3PM of the previous daytime. Data are from all of the nights, whether clear nights or cloudy nights, and only if the Sun is at least 18 degrees below the horizon, and the Moon is at least 10 degrees below the horizon.

Figure C1 is a density plot. The color of each small square in the plot is proportional to the percentage of measurements that fall into that position. Each small square includes one or more of the SQM measurements. The colors are scaled independently for each site. See Puschnig and others (2013) for another example of a density plot of SQM data.

The red and yellow trend in the plot across the darkest sky measurements at the bottom of the plot identifies the very frequent measurements over the time period. We call that red trend the “Most Common Clear Dark Sky Night” or MCC for short. The large sparse, scattered area of blue and yellow color above the red trend represents SQM measurements taken under cloudy skies at night. Both features of the density plot, the dense red trend and the sparse blue pattern above, and other subtleties present, represent the skyglow signature of the site.

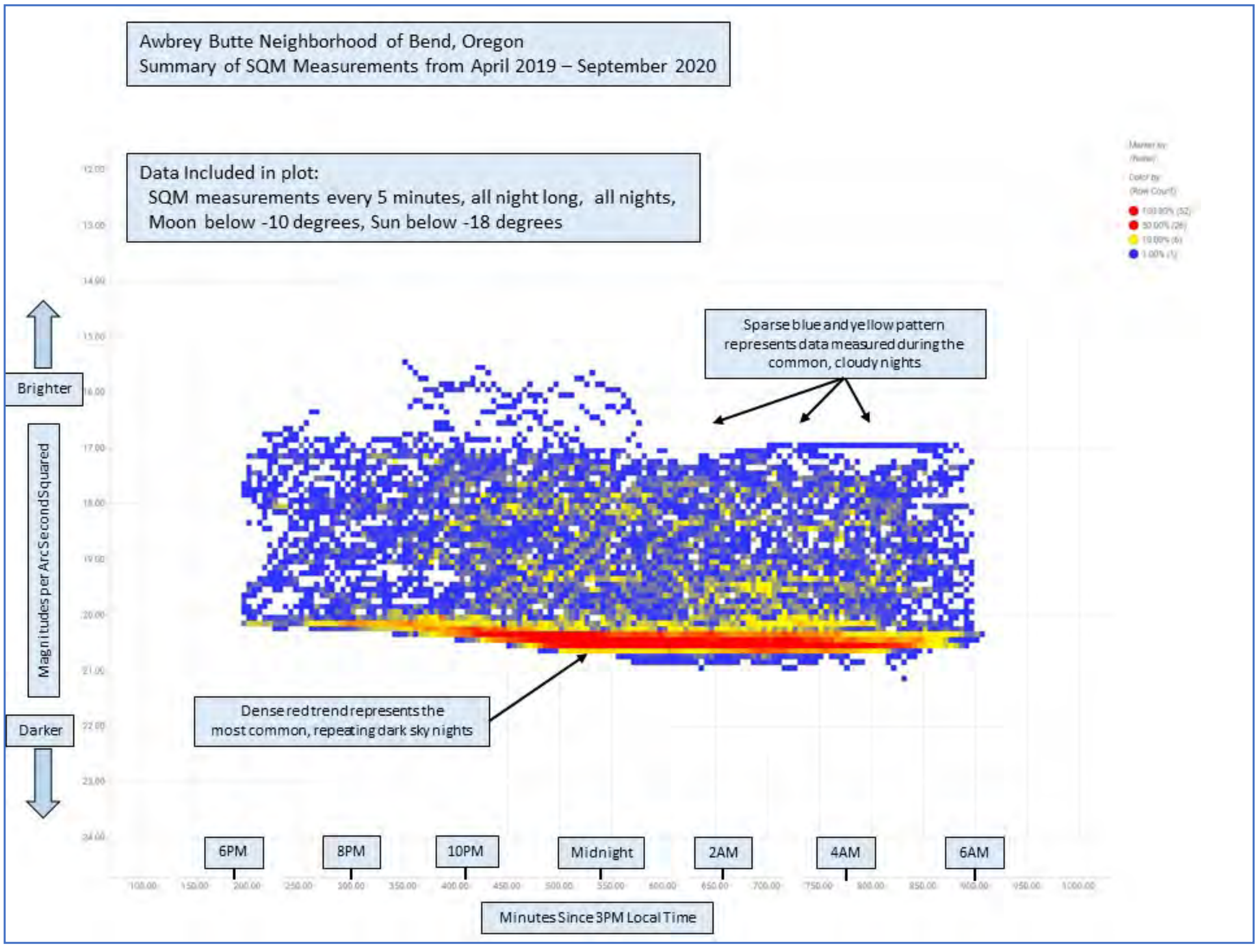
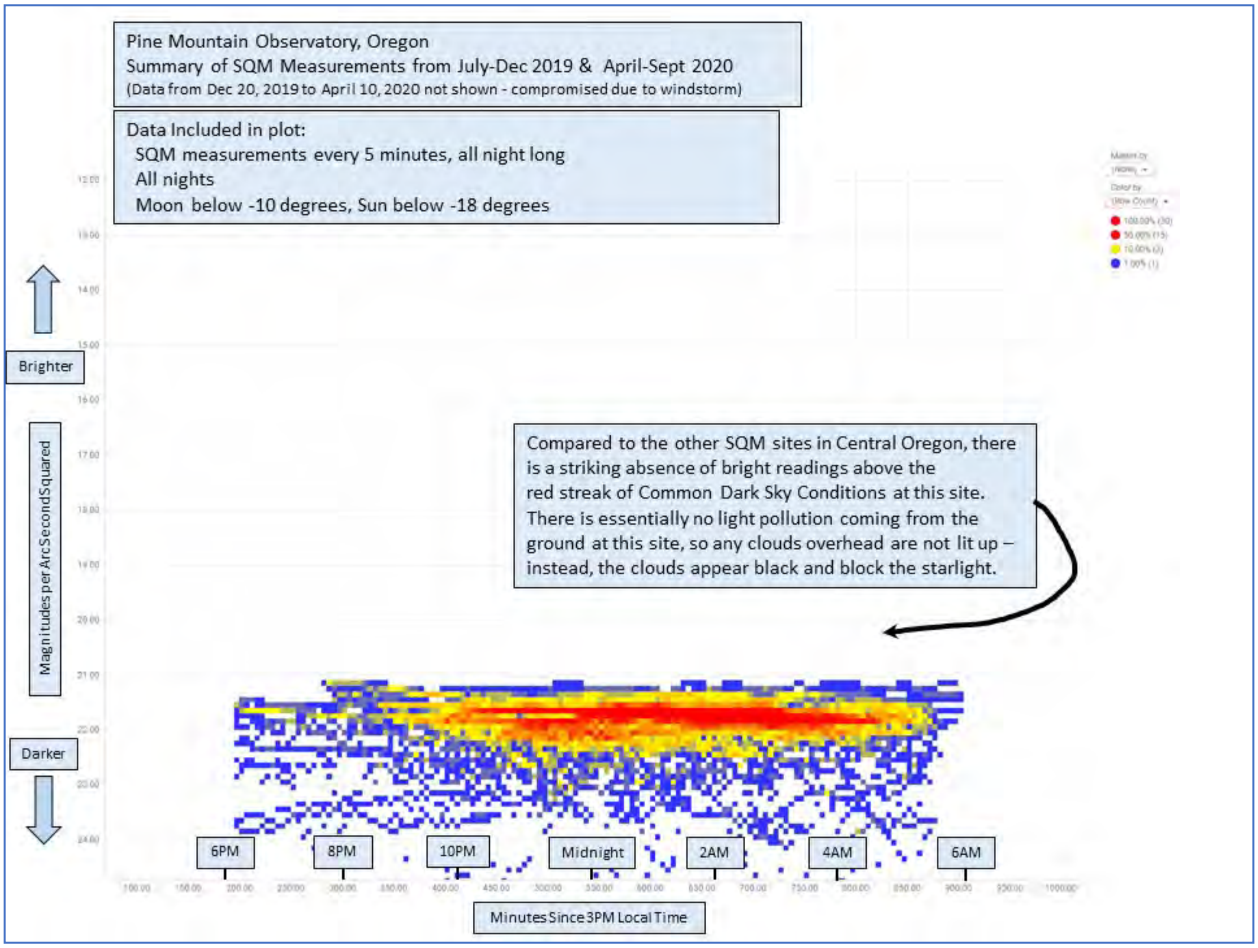


Figure C1. *Density plot of SQM data from the Awbrey Butte Neighborhood site. Each small square represents the percentage of 5-minute SQM samples that fall into that zone. We take the dense red trend across the bottom of the data as the Most Common Clear Dark Sky Nights (MCC). The sparse blue and yellow pattern at brighter skyglow values are due to measurements under cloudy skies at night.*

Figure C2 shows an SQM signature density plot with an entirely different character – from the Pine Mountain Observatory (PMO) site which has very little light pollution overhead. The red and yellow streak of MCC at this site is positioned between 21 and 22 mags/arcsecond^2, and is about 4x darker than the Awbrey Butte site (20 – 21 mags/arcsecond^2). Moreover, the sparse blue pattern of clouds is entirely below the red streak, instead of above it.

This signature is characteristic of dark sky sites -- there is very little light pollution coming from the ground at the PMO site, so any clouds overhead are not lit up from below – instead, the clouds appear black and block the starlight. Because the clouds appear black, the data from cloudy nights plot below the clear night MCC red streak on the plot.


Pine Mountain Observatory, Oregon
Summary of SQM Measurements from July-Dec 2019 & April-Sept 2020
(Data from Dec 20, 2019 to April 10, 2020 not shown - compromised due to windstorm)

Data Included in plot:
SQM measurements every 5 minutes, all night long
All nights
Moon below -10 degrees, Sun below -18 degrees

Compared to the other SQM sites in Central Oregon, there is a striking absence of bright readings above the red streak of Common Dark Sky Conditions at this site. There is essentially no light pollution coming from the ground at this site, so any clouds overhead are not lit up – instead, the clouds appear black and block the starlight.

Figure C2. *Density plot of SQM data from the Pine Mountain Observatory site. Note the absence of bright readings above the red and yellow streak of MCC at this site. See explanation in the figure and in the text.*

Figure C3 summarizes the density plots for all of the SQM sites in the Oregon SQM Network which have been recording up to November 2022. The plots are arranged from top left to bottom right, from most light-polluted to least light-polluted. Some sites have been recording for shorter periods, so they show more sparse density plots. Appendix A summarizes the data available over time for each site.

Notice that the red streak in each successive plot of Figure C3 falls lower, toward darker readings. In that progression, there is a trend for cloudy conditions – the sparse blue points – to fall above the red streak for the light-polluted sites, and to fall below the red streak for the darker sky sites. Anomalies are present in that pattern, which require further work to understand. For example, (a) the Stub Stewart and Mt Pisgah sites show a pattern of sparse darker readings below the red streak, and (b) the Cottonwood Canyon site shows readings above the red streak.

In the first years of this project, we considered that the characteristic red and yellow streak of our initial sites in Oregon, which were in the relatively dry, high desert environment of central and eastern Oregon, might not appear in other climatic areas of Oregon. However, we note that the two sites in Portland, and the Mt Pisgah, Junction City and Lowell sites in the Willamette Valley, the Bandon site on the Oregon coast and the Oregon Caves site in the southwest mountains, which all have a non-arid, Mediterranean climate, also show the high-density pattern.

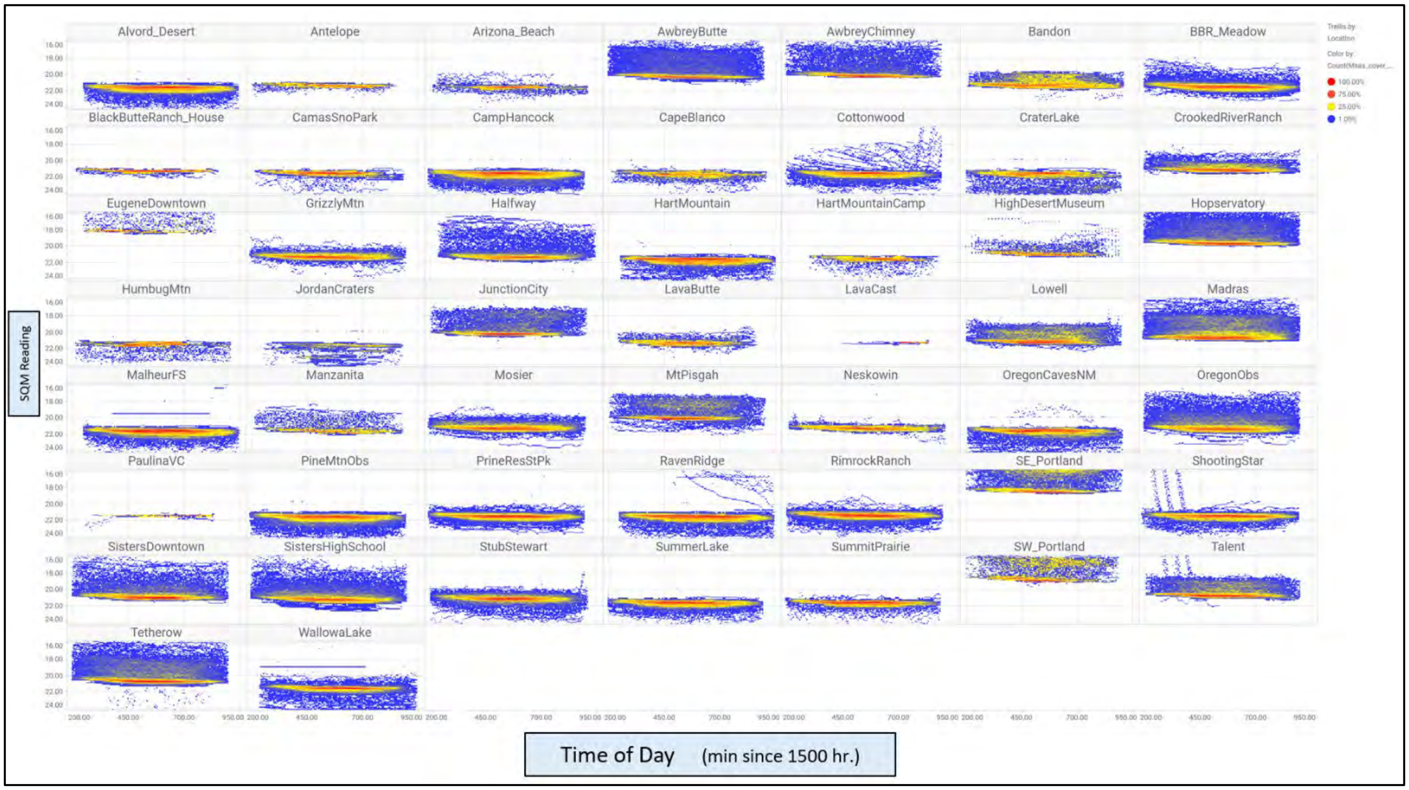


Figure C3. *Density plots of SQM data from the sites with data available to November 2022.*

Figure C4 shows the data for all of the sites after "jaggy" data – cloudy data – removal by the algorithm described in Appendix B and after deleting data higher than the 22.0 or 22.1 magnitudes/arc second squared cutoff. Note that the algorithm failed to remove cloudy data from periods of uniform overcast or fog – there are smooth blue lines above and below the high-density points at many of the sites in Figure C4, especially for the more light-polluted sites near the top of the Figure.

In previous editions of this report, we manually deleted those points above and below the high-density red/yellow zones at each site. Beginning with Edition #7 of this report series, we employed an automatic spatial filter, described in Appendix B, to remove the sparse points which passed through the cloud filter. The cleaned, cloud-free data are shown in Figure C5.

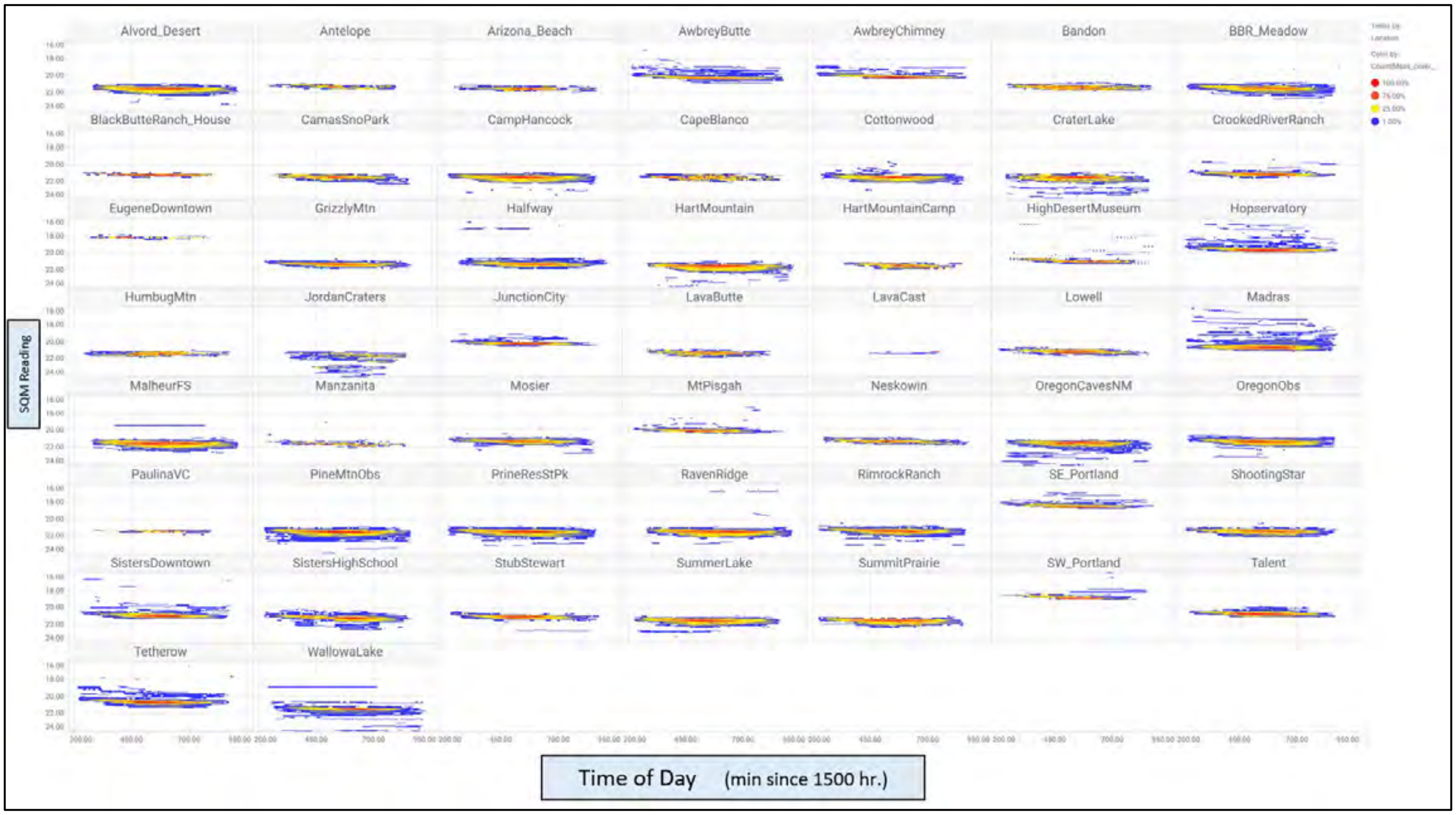


Figure C4. *Density plots of SQM data from all 45 sites after application of the cloud removal algorithm. The algorithm fails to remove cloud cover that is consistent over time – the blue points above and below the high-density zones.*

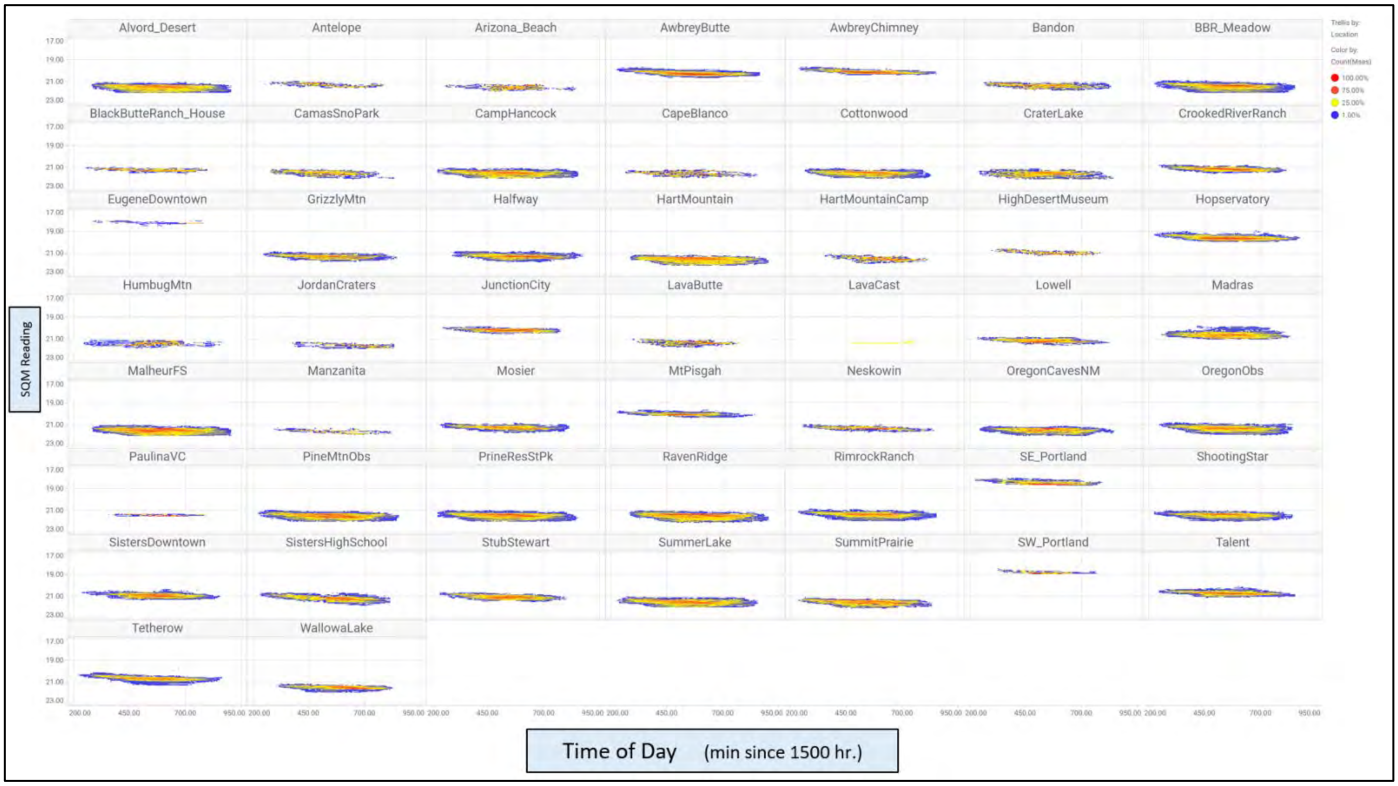


Figure C5. *Density plots of SQM data from all sites after automatic cleaning of the smoothly-varying cloudy data. Because the SW_Portland site has so little data to date, we did not apply the cleaning to that site's data.*

We note that for some of the darker sites, for example, the Crater Lake SQM site, that a number of clear nights show valid data darker than 22.0 to 22.1 magnitudes/arc second squared. Accordingly, we applied the 22.1 cutoff to those sites, which are: Camas Sno Park, Crater Lake, Hart Mountain, Hart Mountain Camp, and Raven Ridge. We applied a 22.0 cutoff to all of the other SQM sites.

Appendix D – Darkening over time with aging of SQMs

Recent research (Puschnig and others, 2020; Fiorentin, 2023) documents that as the SQM device and weather proof enclosure age, that there is a darkening effect on measured data. Puschnig and others 2020 estimate an average darkening of about .04 mags/arcsecond^2 per year. Fiorentin, 2023, found darkening up to 0.30 mags/arcsecond^2 in SQMs exposed for 9 years. This aging will darken the skyglow measurements over time.

Unihedron (personal communication, 2022) notes that two issues can be involved: 1) development of a translucent film on the blue glass IR filter, which seems related to moisture and 2) yellowing of the plastic case of the semiconductor sensor over time.

Also, Unihedron (personal communication, 2022) notes that SQMs manufactured before late 2013 used a plastic rectangular lens plate on the meter (not the weatherproof housing) that could yellow with age. SQMs manufactured after late 2013 use a glass plate which is not subject to aging. The SQMs used in our project date from 2019 onward.

To understand this phenomenon better, we obtained two new SQMs and installed them to run in parallel to two SQMs, which had been running for about three years. We installed one at a light polluted site (Awbrey Butte) and the other at a dark sky site (Prineville Reservoir State Park). Both ran in parallel for several weeks.

Figure D1. New and old SQMs running in parallel at two different sites, with the goal of assessing aging phenomena of the SQM unit. Awbrey Butte site on the left, Prineville Reservoir State Park on the right.

Figure D2 shows the results of this experiment.

	AwbreyButte	AwbreyButte_Parallel	PrineResStPk	PrineResStPk_Parallel
Count	819	814	366	373
Avg	20.404090	20.351351	21.766366	21.715764
Median	20.440000	20.380000	21.810000	21.760000
Outliers	14	1	6	0

Figure D2. Box plot comparing data recorded by the two sets of parallel-running SQMs. In both cases, the older SQMs recorded slightly darker skies on average.

Table D1 summarizes the statistics of this experiment.

SQM	SQM ID	Install Date	End of Test Date	SQM Exposure (days)	SQM Exposure (Years)	Difference of Exposure (years)	Count	Average	Median	Msas Difference of Average	Msas difference per Exposure Year
Awbrey Butte Old SQM	A5055IWP	13-Mar-19	2022-02-20	1075	2.9452		819	20.404090	20.44		
Awbrey Butte New SQM	ABSCDE1J	22-Jan-22	2022-02-20	29	0.0795	2.8658	814	20.351351	20.38	0.052739	0.018403188
Prineville Old SQM	AK06E3YZ	30-Jun-19	12-Feb-22	958	2.6247		366	21.766366	21.81		
Prineville New SQM	ABSCDQTV	30-Jan-22	12-Feb-22	13	0.0356	2.5890	373	21.715764	21.76	0.050602	0.019544688
										Mean	**0.018973938**

Table D1. The older SQM in each case recorded an average value .05 magnitudes per arc second squared darker than the new SQM in parallel. This amounts on average to .019 per year of exposure.

Distributed over the time range of exposure difference, we estimate a darkening of about .019 magnitudes per arc second squared per year of exposure. Accordingly, we subtract values proportional to this assumed aging effect progressively from our data, based on the serial exposure time of each data point of each SQM in our network.

Puschnig and others 2020 had three SQM sites at widely different locations, ranging from about 48 to 60 degrees North latitude. They noted aging proportional to the latitude of exposure, with less darkening at higher latitudes, related to the amount of sunlight exposure at each site. Figure D3 plots the Puschnig and others aging data versus latitude. Given that data, the Oregon SQMs at about 44 degrees north latitude should have a darkening at about .06. Instead, we find a darkening of less than .02.

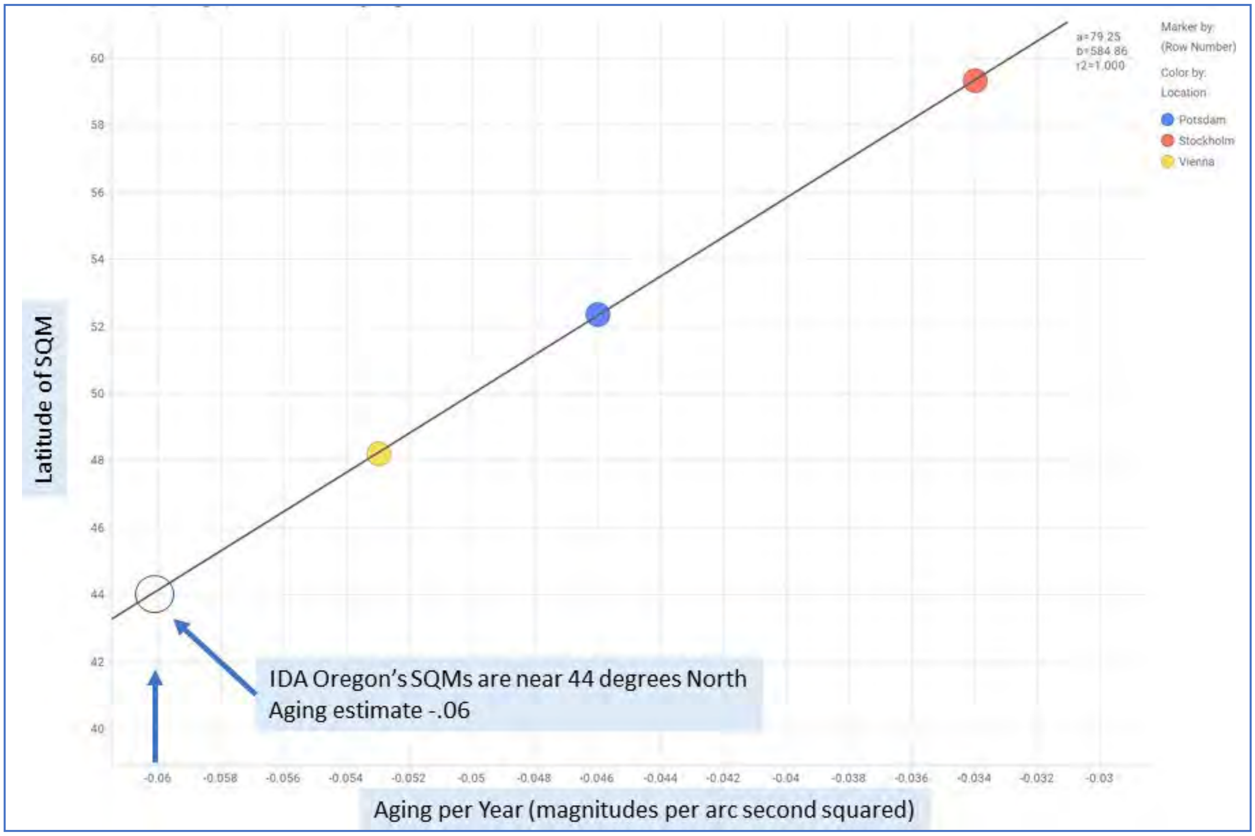


Figure D3. Data on aging of SQMs from Puschnig and others, 2020. There is a strong relationship of latitude on the rate of aging. Based on the three SQMs in their data set (colored dots) the Oregon SQMs should have an aging rate of about .06 per year. Our current experimental data suggest a smaller aging rate of slightly less than .02 per year.

Our parallel SQM experiment only involved two pairs of SQMs. Additional experimental data along with re-calibration of older SQMs should shed additional light on this. It could be that our observations of older SQMs recording darker values are not caused by darkening, but by some other calibration issue. We currently attribute the difference to aging of the older SQM. We have implemented the approximately .02 per year aging adjustment in our data processing in this report.

Appendix E – Adjustment for airglow related to solar flux

A factor to consider in zenith skyglow trends over long periods is variations of airglow, the light emitted from the atmosphere itself due to the impact of space weather on Earth (Grauer and others, 2019; Grauer & Grauer, 2021). Airglow is known to vary on a wide range of time scales, from rapid variation in minutes and across one night, to strong, years-long changes correlated to the 11-year solar sunspot cycle. We focus on an estimate of the long-term change of airglow.

The sun is currently rising out of a solar sunspot minimum, toward a predicted sunspot maximum in July 2025 (Figure E1). So, space weather may cause our SQM data to read brighter since our SQM project began in mid-2019, by increased airglow, independently of any changes in light pollution from the ground.

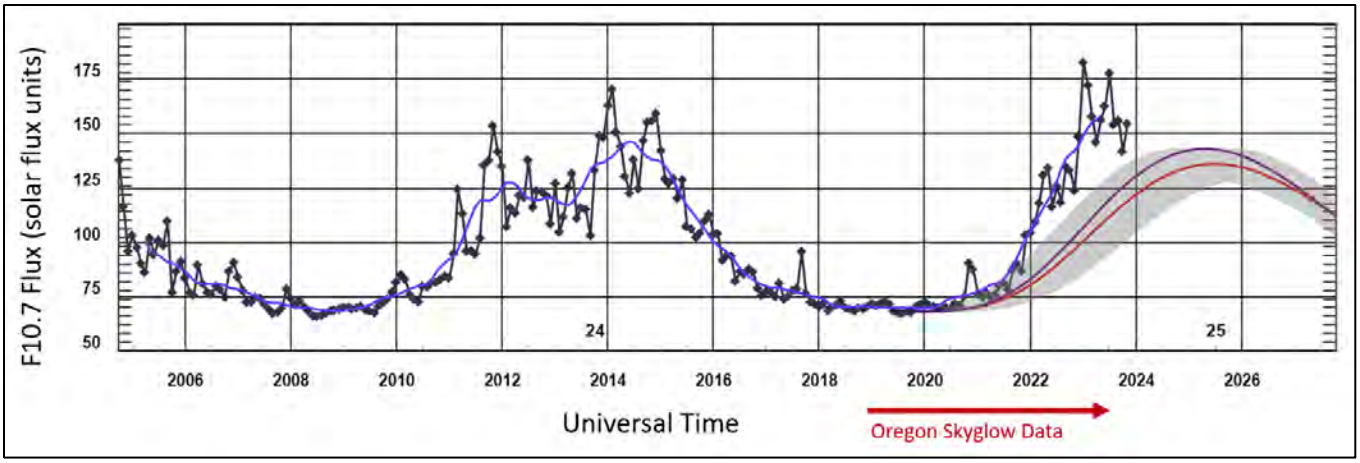


Figure E1. Solar cycle progression from NASA's Space Weather Prediction Center. The current time span of SQM data is shown by the horizontal arrow in the lower right. (Figure is from https://www.swpc.noaa.gov/products/solar-cycle-progression)

We use the hourly solar flux data from the Canadian Solar Radio Monitoring Program to estimate the contribution of natural airglow to the visible band zenith sky brightness at two sites which we expect have not changed due to artificial light, and subtract that estimate from our measured SQM data. We use the hourly solar flux measurement which is closest in time, after 4.5 days, to our individual SQM measurements. The 10.7 cm Solar Flux arrives from the sun at the speed of light. Any associated solar wind and storms that impact airglow travel much more slowly and arrive at Earth about four days later. Following Krisciunas and others, 2007, we employ a 4.5 day offset to associate any night time airglow with the arrival of solar phenomena on the day side of the Earth, a half day earlier.

Figure E2 is a plot of the 10.7 cm Solar Flux on the horizontal axis versus the SQM data from both the Prineville Reservoir State Park and the Pine Mountain Observatory sites. We expect that the zenith sky brightness has not changed at these sites due to artificial light. Under that assumption, the upward trend of the regression line in Figure E2 is an estimate of the impact of the changing solar flux on the zenith sky brightness. The SQM data is subsequently adjusted downward according to the associated Observed Solar Flux during acquisition.

Figure E3 is the same plot of data, after flattening the trend – after applying an adjustment for the implied brightening of the night sky due to the Observed Solar Flux. The adjustment forces the linear regression to be flat at an Observed Solar Flux value of 60 solar flux units, which is about the average of the solar flux during its quiescent periods.

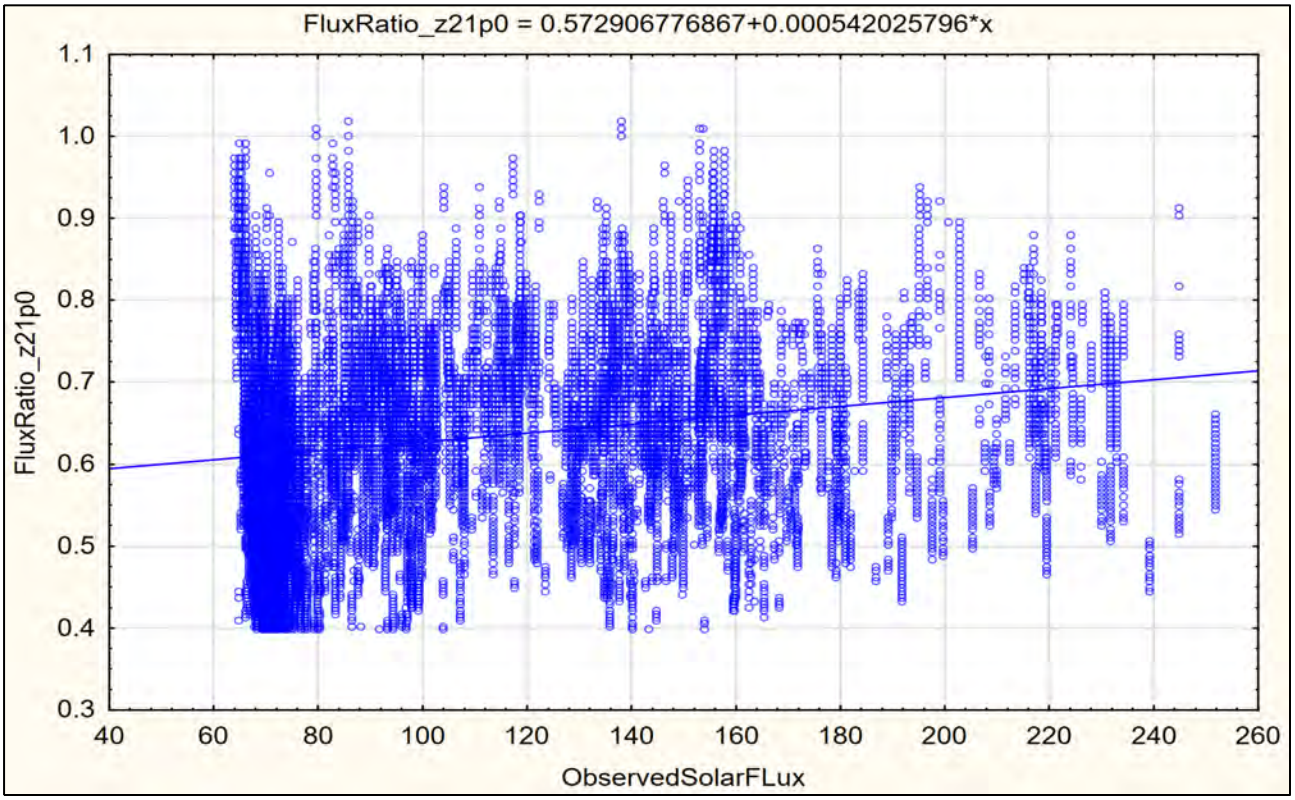


Figure E2. The vertical axis plots SQM data in linear Flux Ratio domain from Pine Mountain Observatory and Prineville Reservoir State Park, both dark sky sites which we assume have not changed in zenith skyglow over the duration of the SQM survey. The horizontal axis is the 10.7 cm Observed Solar Flux, associated with the SQM data and offset by 4.5 days. The linear regression shows an increase in brightness at the zenith of about 0.1 flux units across the range of the Observed Solar Flux. See text for additional comments.

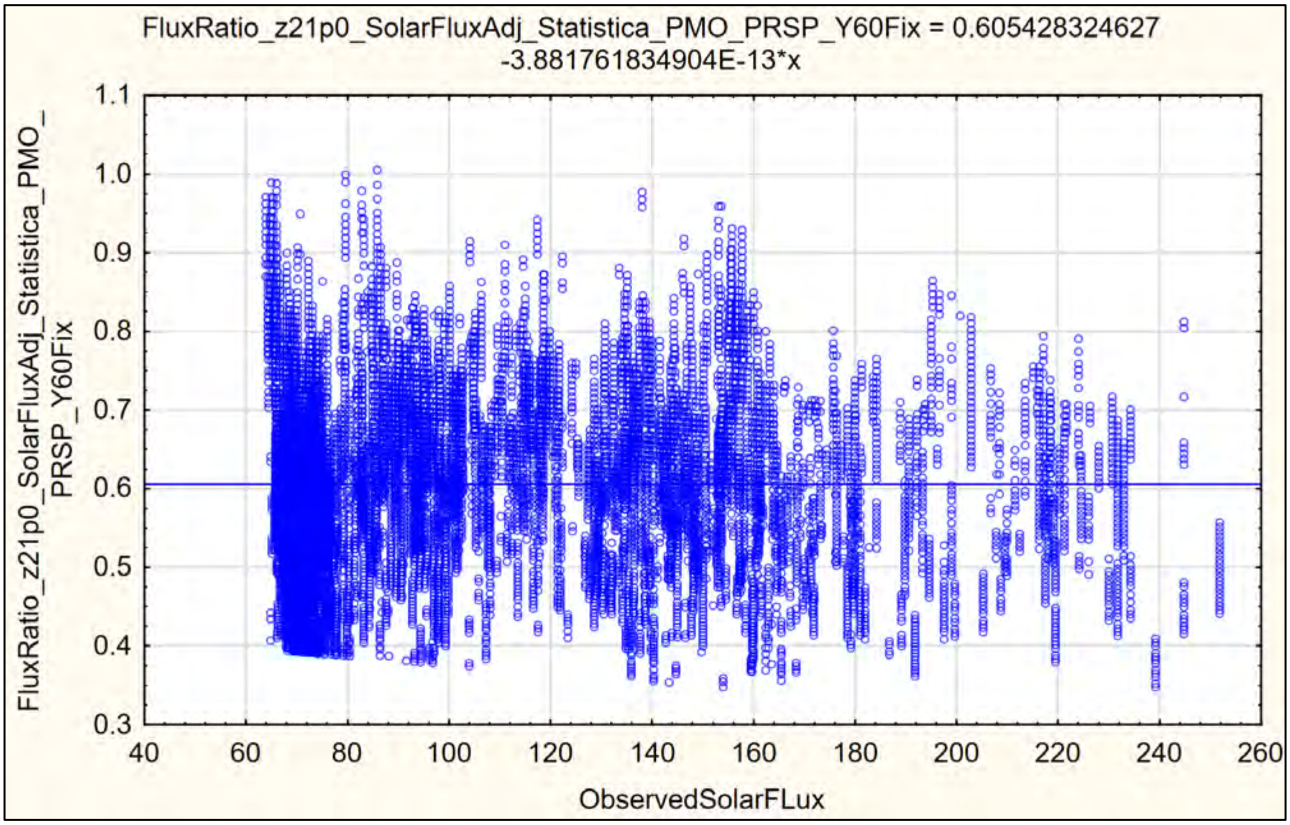


Figure E3. Same plot as Figure E2, but after flattening the implied brightening due to increased solar flux. The regression line is now essentially flat.