Measuring Skyglow in Central Oregon by SQM, Photographic and Satellite Methods

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International Dark-Sky Association
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Introduction

- Why attend this talk? -- Learn how to create a sky quality measurement program to support dark sky advocacy in your community

- What questions do you hope to answer by gathering sky brightness data?
- We provide:
  - Our questions,
  - A range of sky brightness measurement options, and the
  - Answers to our questions from our experience in Central Oregon.
- The tools and methods we employ are commercially available and readily applied

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What Questions did we have in Oregon?

- What area first? - Central Oregon – Why?
  - The rapid growth of population in the region
  - Probable increase of skyglow as a result
  - Presence of observatories and interested people.

- What's the current level and extent of light pollution?
- Is the light pollution getting worse?
- Do we have candidate Dark Sky Areas?
- Can our information help decision-makers to improve lighting ordinances in Central Oregon?
- How do cities in Central Oregon compare in upward light trends to other cities in the western US?

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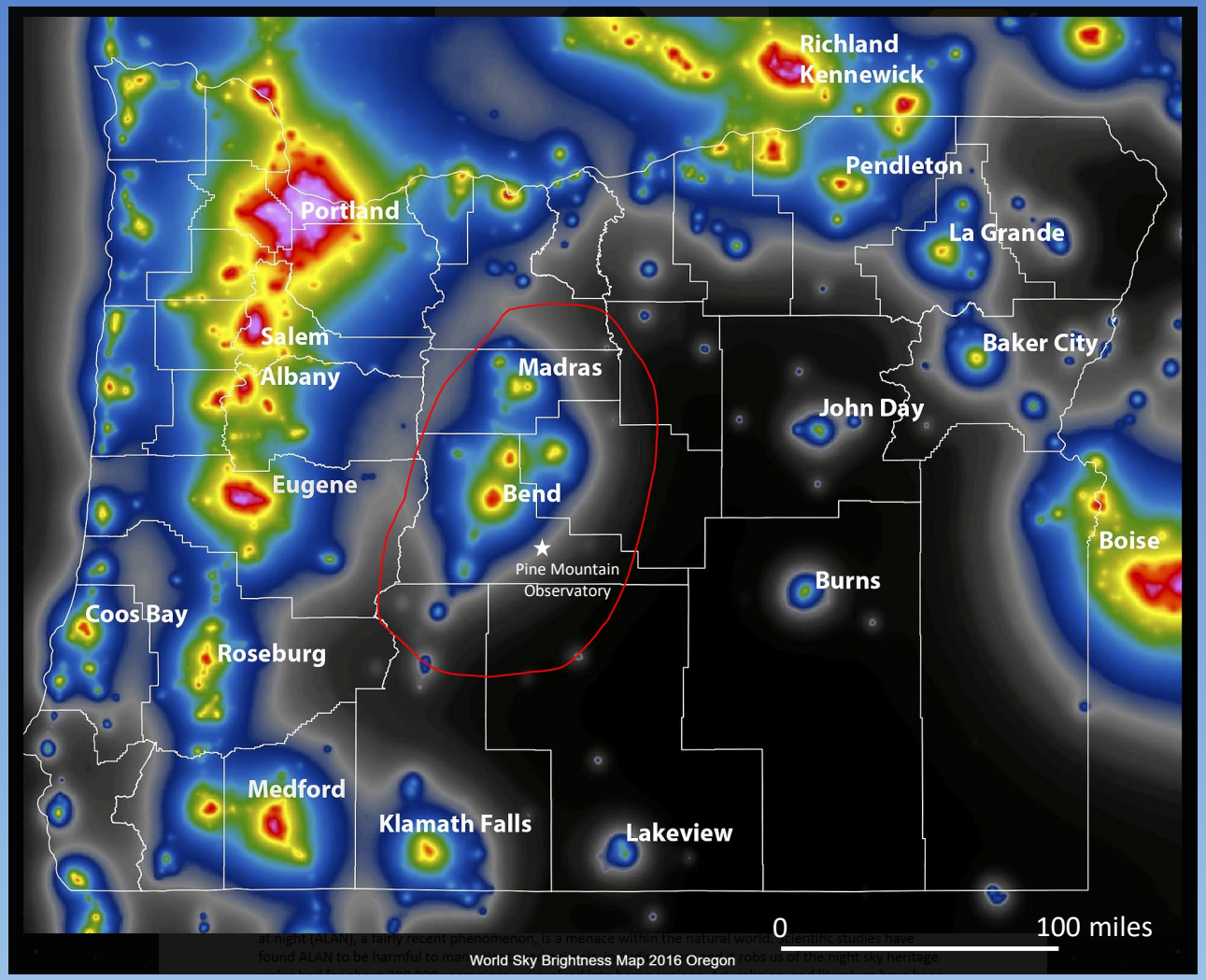
New World Atlas of Artificial Night Sky Brightness (2016) – Light pollution in Oregon



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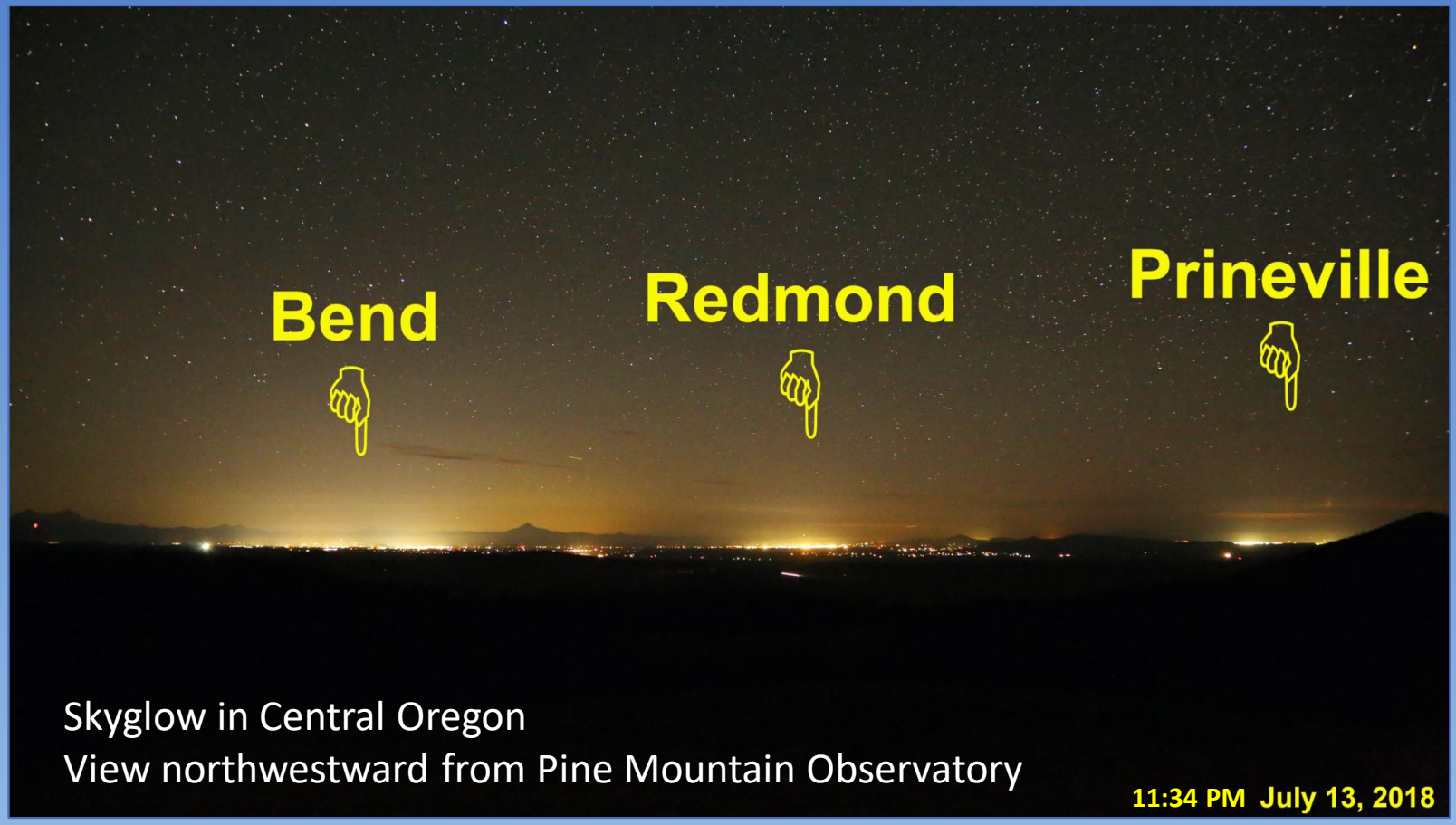
Qualitative Observations Example – Light Domes in Central Oregon



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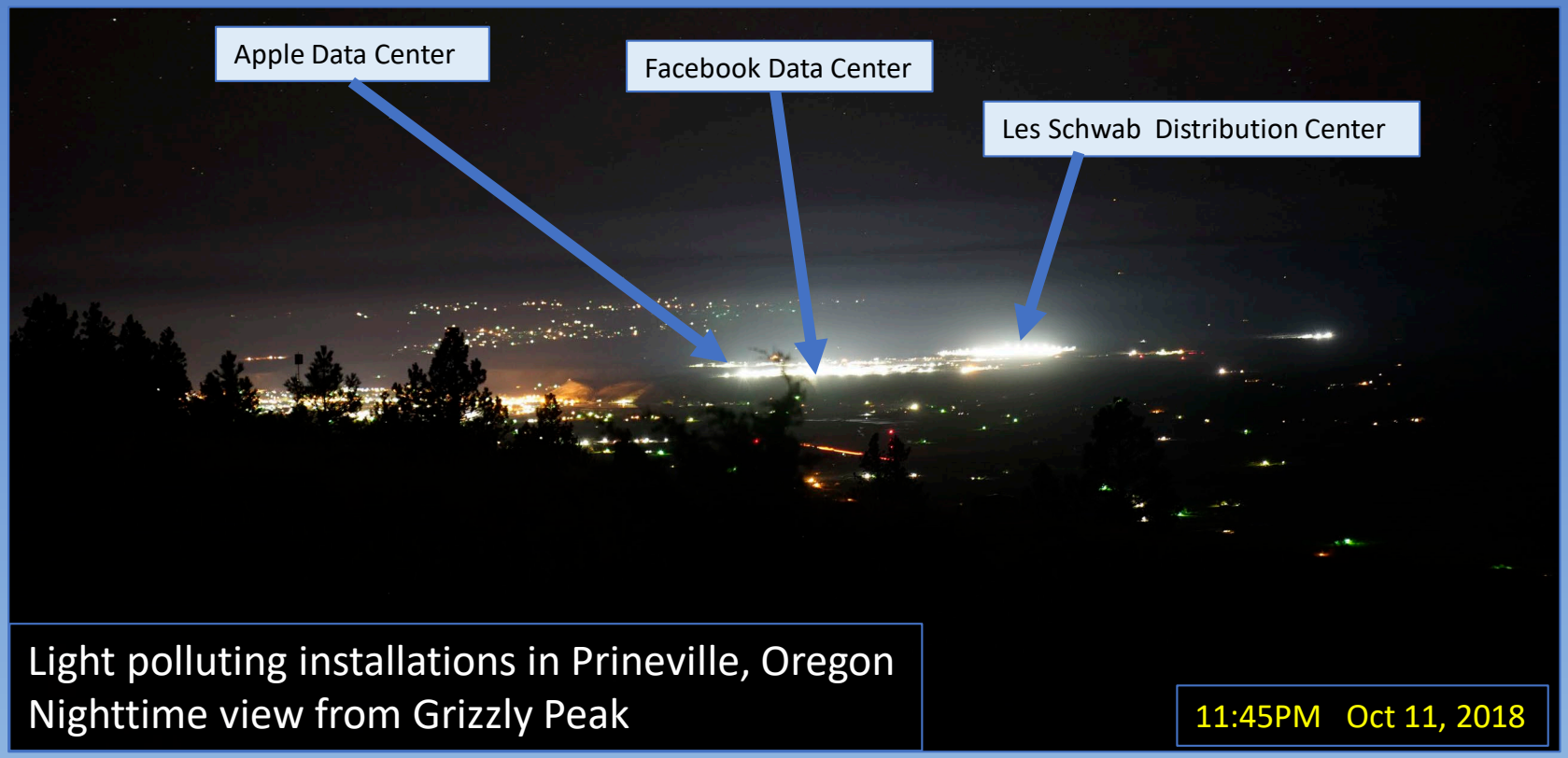
Qualitative Observations - Significant contributors to skyglow in Central Oregon



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Our measurement program considers these dimensions

Area of Interest

- At a proposed dark sky place?
- In a city and outskirts with lights encroaching?

Time Frame

- Several nights, a few measurement samples?
- Several nights, all night long?
- Many nights, over weeks and years?

Direction of View

- Directly overhead?
- In all directions - hemispherical?
- Looking down, from above?

Type of Data

- Published maps?
- Sky Quality Meter (SQM) zenith sky brightness (ZSB) measurements? Fixed or Moving?
- Qualitative all-sky imaging?
- Quantitative all-sky brightness mapping?
- * Photos from airplane or drone?
- Nighttime satellite images?

*Not yet

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We are using four methods in our skyglow measurement campaign

1) SQM zenith, long term monitoring from fixed locations
2) SQM zenith, profiles from moving vehicle
3) Simultaneous all-sky fisheye photography, SQM zenith measurements, and SQM hemispheric sky brightness mapping at critical locations
4) Nighttime satellite images of the Earth

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Method 1 - SQM zenith monitoring at fixed locations

Area of Interest

- At a proposed dark sky place
- In a city and outskirts with lights encroaching

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- Published maps?
- SQM zenith measurements. Fixed. or Moving?
- Qualitative all-sky imaging?
- Quantitative all-sky brightness mapping?
- Photos from airplane or drone?
- Night-time satellite images?

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Method 1 - SQM zenith monitoring at fixed locations

- Photometer with a narrow field of view (20 deg FWHM)
- Detects visible light
- Controllable frequency of measurement (1 second to minutes between samples)
- Different models – LU-DL records internally ($290) or
  – LU records to laptop ($230)
- Commonly used in skyglow research projects
- Made by Unihedron of Canada

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Method 1 - SQM zenith monitoring at fixed locations

- SQM-LU-DL in a weatherproof enclosure
- One measurement every 5 minutes
- Runs day and night, batteries last about 3 months
- Download data monthly to laptop by USB cable

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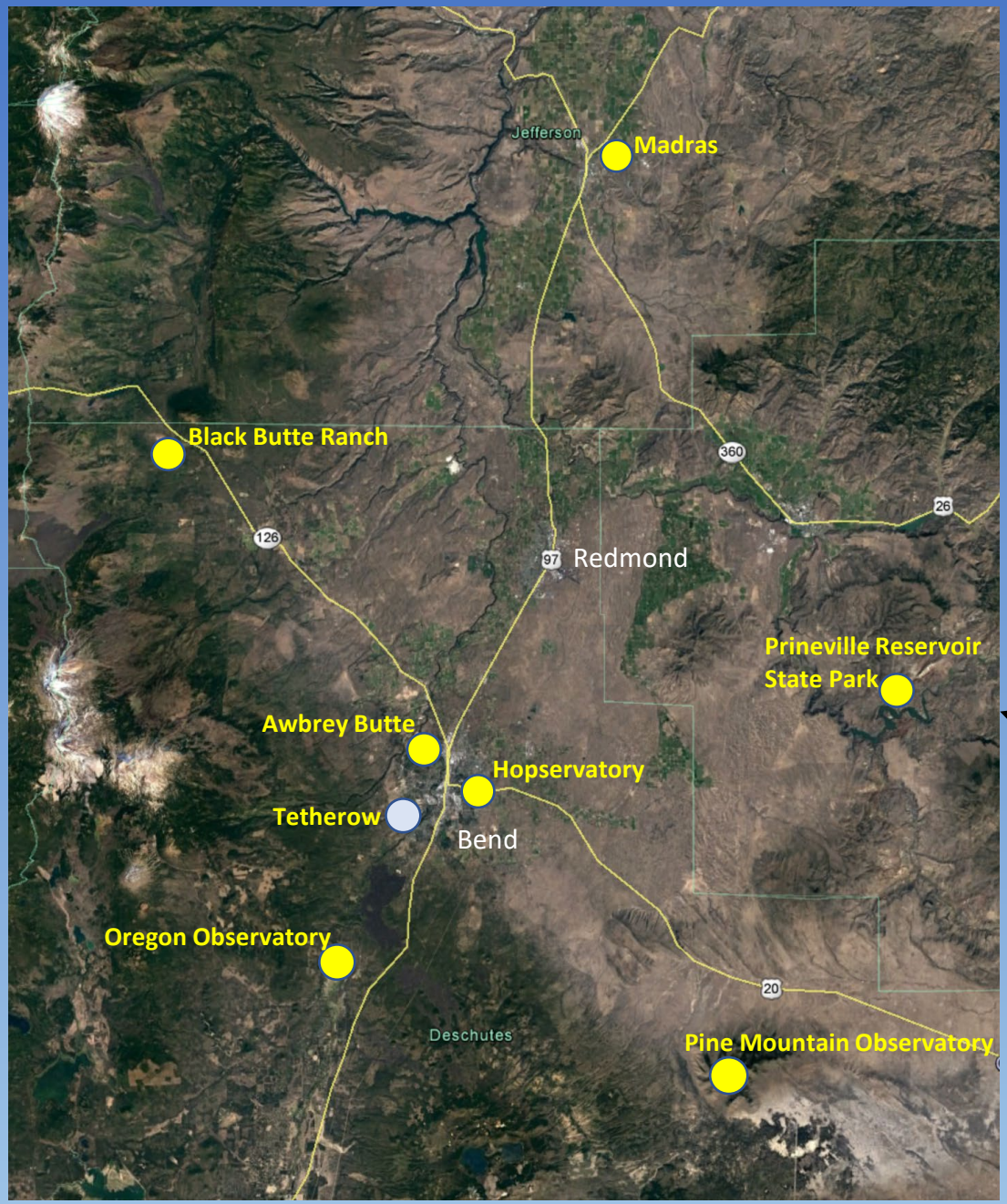
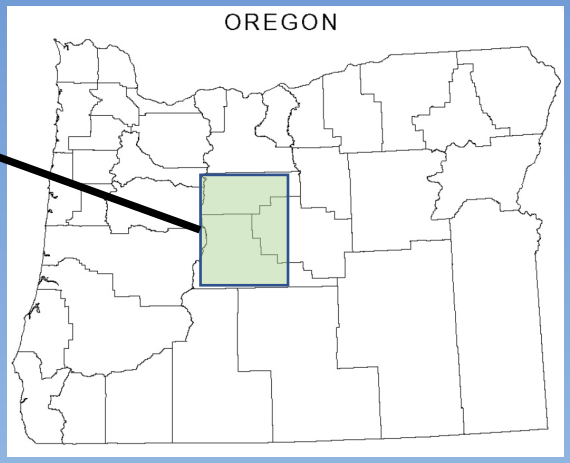
Method 1 - SQM Zenith monitoring at fixed locations



Central Oregon Skyglow Measurement Network

Operating at present

Planned



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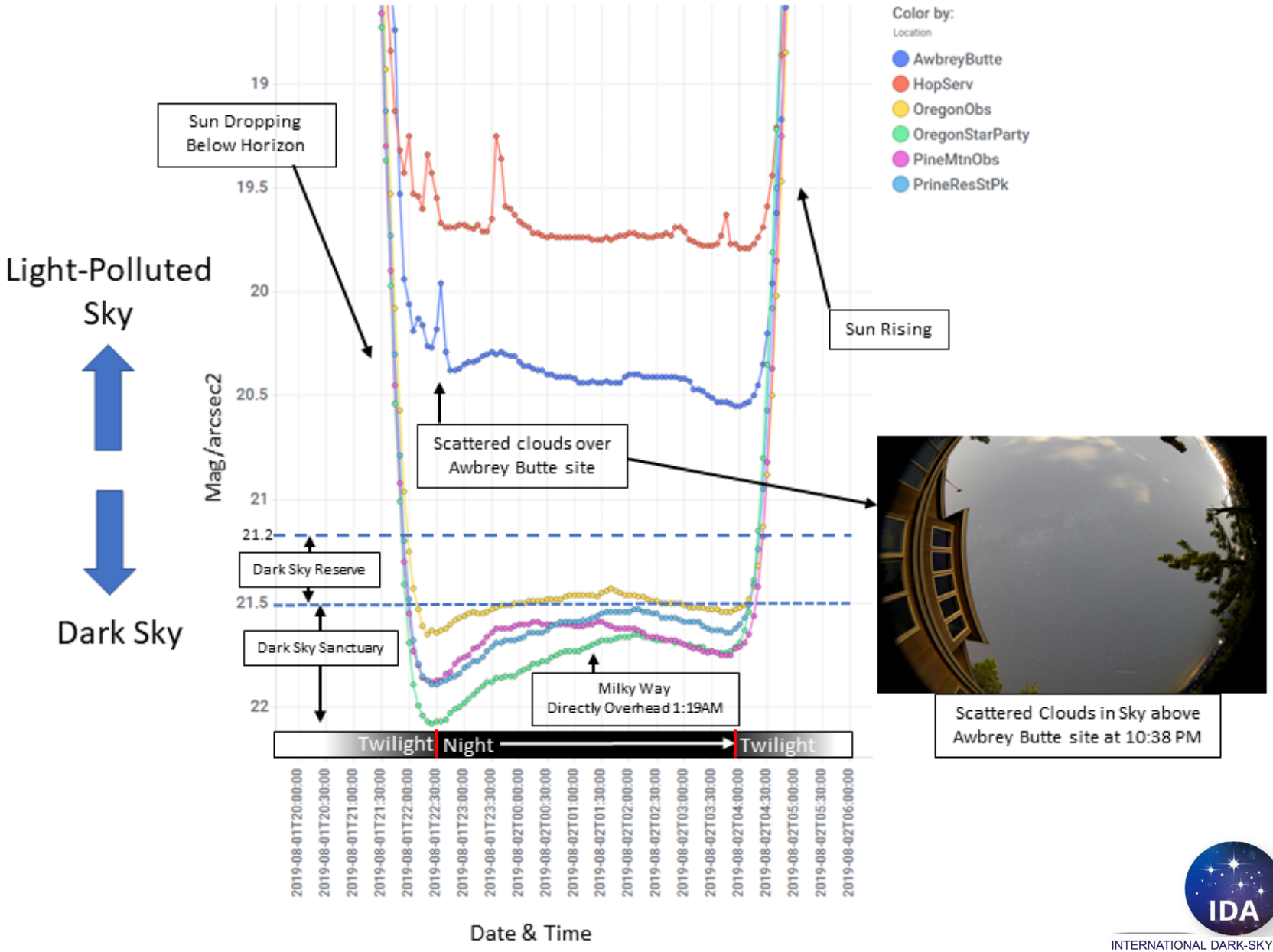

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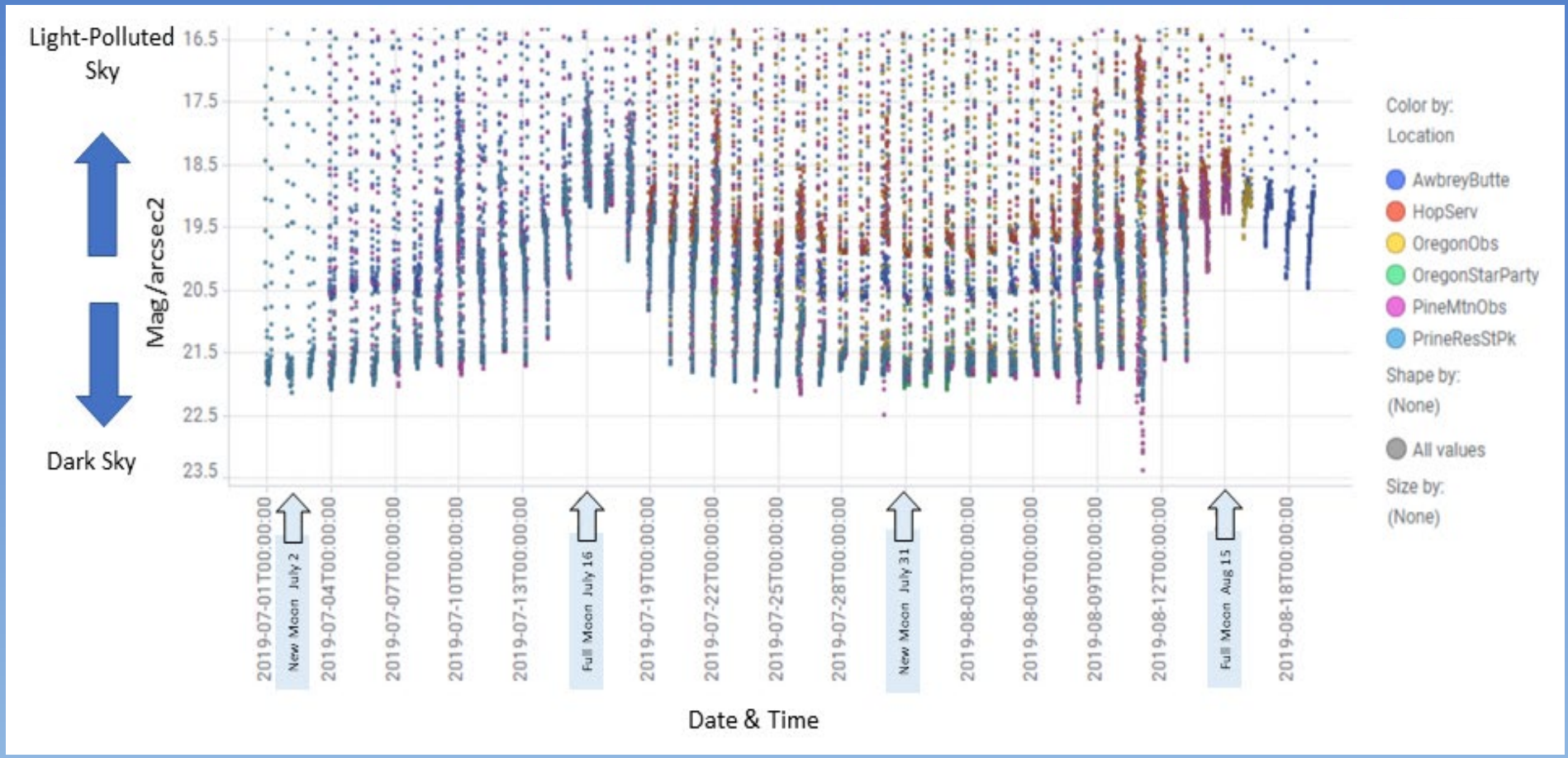
Method 1 - SQM zenith monitoring at fixed locations

First Data from SQM Network July to Mid-August 2019



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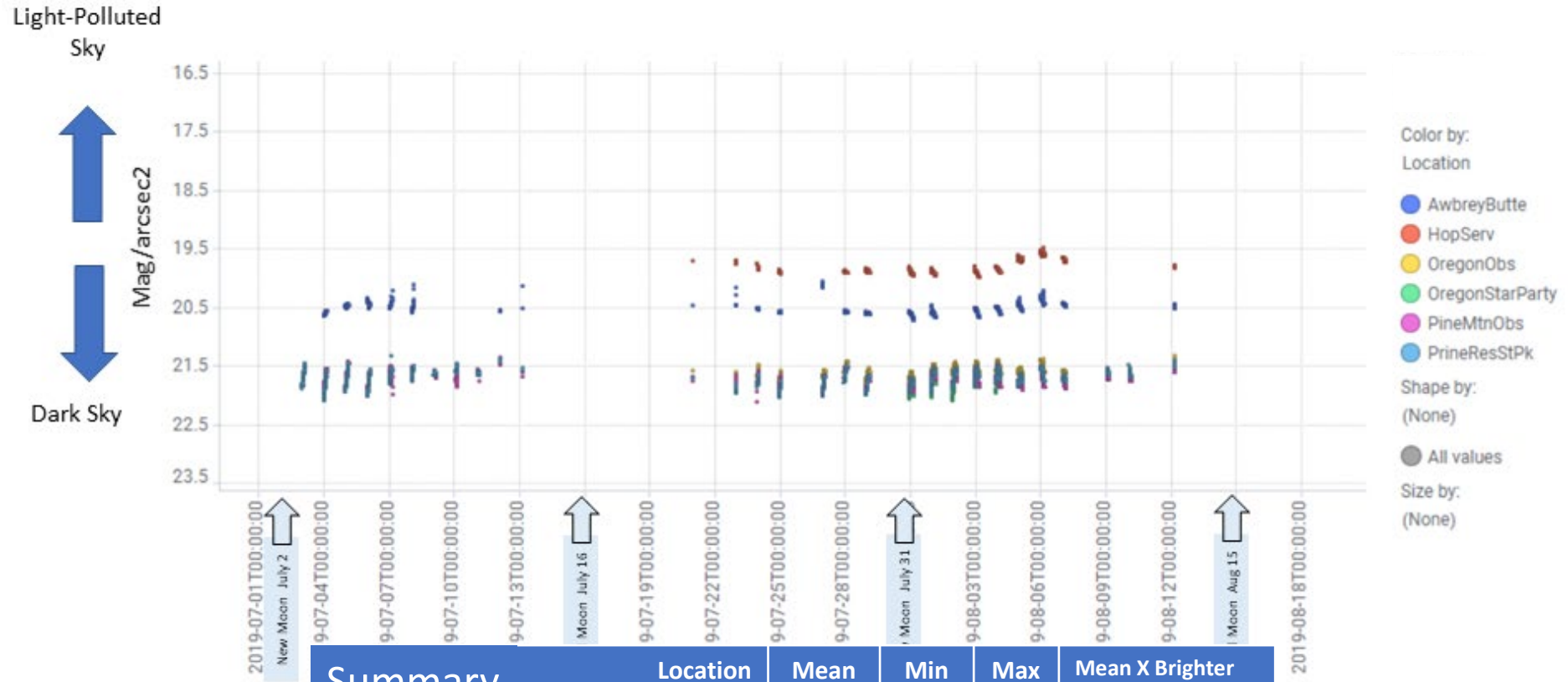
Method 1 -- After eliminating the data adversely affected by sun, moon and clouds



Summary Statistics

Location	Mean	Min	Max	Mean X Brighter
Oregon Star Party	21.8	21.6	22.1	1.0 X
Pine Mtn Observatory	21.7	21.3	22.6	1.1 X
Prineville Reservoir State Park	21.7	21.3	22.1	1.1 X
Oregon Observatory	21.6	21.2	21.8	1.2 X
Awbrey Butte	20.5	17.6	20.7	3.3 X
Hopservatory	19.8	17.2	20.0	6.3 X

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Method 2 - SQM zenith profiles from moving vehicle

Area of Interest

- At a proposed dark sky place
- In a city and outskirts with lights encroaching

Time Frame

- Several nights, a few measurement samples?
- Several nights, all night long
- Many nights, over weeks and years?

Direction of View

- Directly overhead
- In all directions - hemispherically?
- Looking down, from above?

Type of Data

- Published maps?
- SQM zenith measurements. Fixed or Moving
- Qualitative all-sky imaging?
- Quantitative all-sky brightness mapping?
- Photos from airplane or drone?
- Night-time satellite images?

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Method 2 - SQM zenith profiles from moving vehicle

- Motivation – measure impact of population center on night sky brightness over surrounding region

- SQM measures at 1-sec intervals
- GPS simultaneously records position
- Laptop controls measurements and records ZSB and position data
- Measured on clear, moonless nights
- Rapidly measure ZSB over large area at high sample density
- Document spatial variation in ZSB
- Use data from fixed, dark sky reference stations to correct for temporal changes in ZSB over the course of the traverses

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Method 2 - SQM zenith profiles from moving vehicle

Through Goldendale, WA to Rock Canyon – Unihedron export to KML displayed in Google Earth with New World Atlas overlay.

Data point markers use the same color scheme as the New World Atlas of Artificial Night Sky Brightness.

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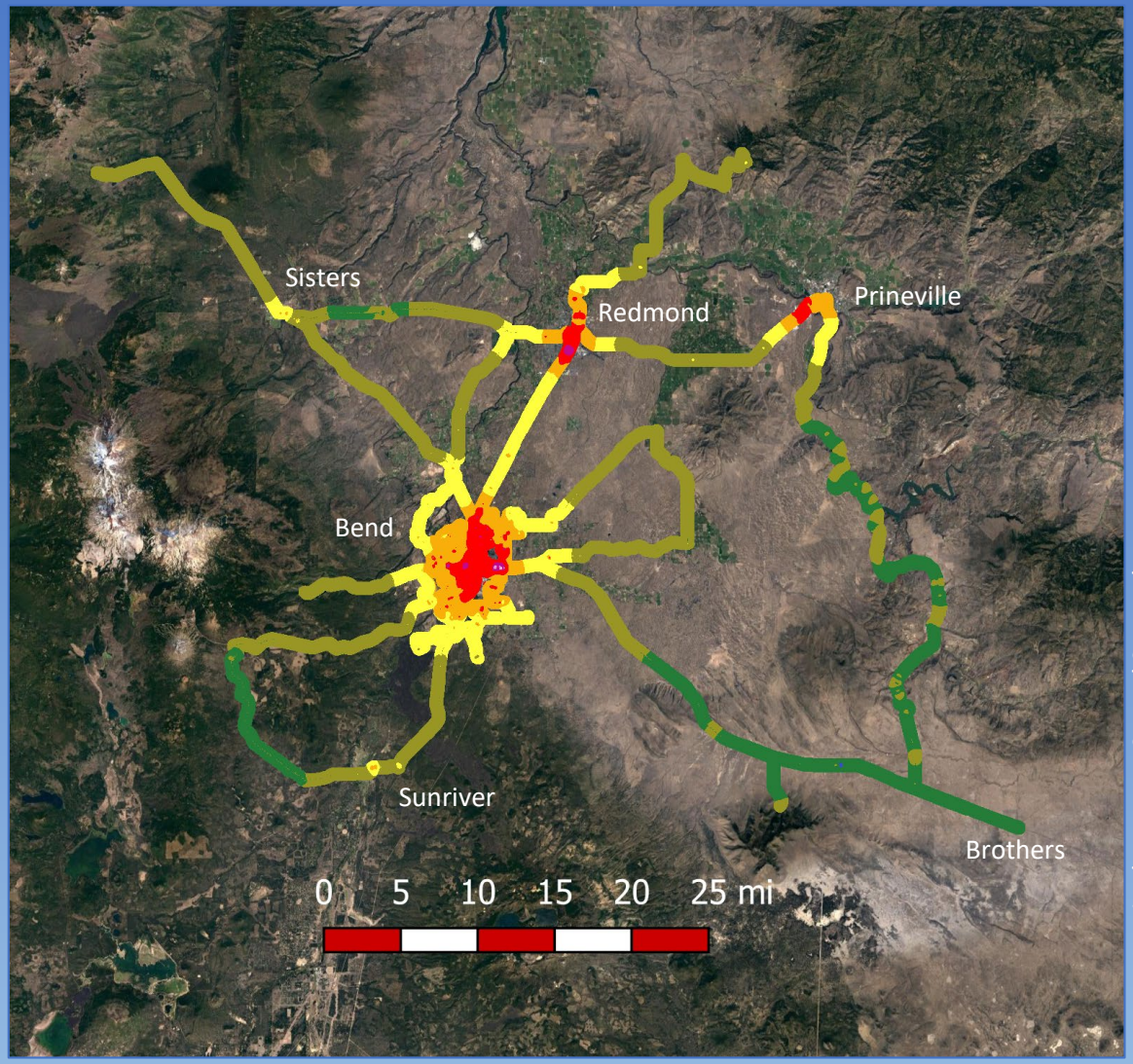
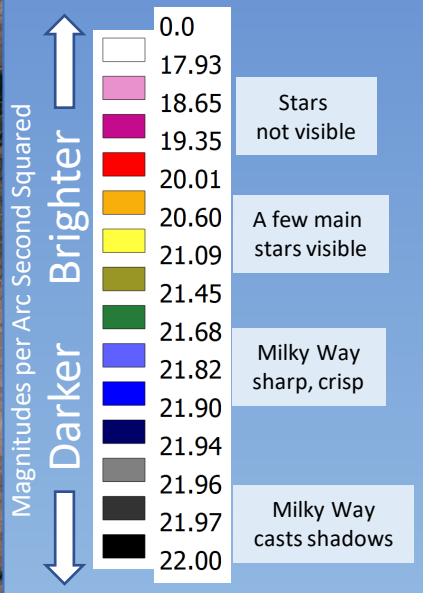
Method 2 - SQM zenith profiles from moving vehicle





GIS software provides greater flexibility in processing and plotting SQM zenith profile data.

Central Oregon Skyglow Map – SQM zenith profiles from October 2018. Plotted using QGIS mapping software.

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Method 2 - SQM Zenith profiles from moving vehicle

Issues:

- Filtering out artifacts
  - Overhead lights
  - Headlights of following or approaching vehicles
  - Headlight scatter off landscape (trees, cliffs, etc.)
- Correcting for temporal changes in regional ZSB
  - Regional ZSB will be changing during the traverses
  - Use contemporaneous ZSB data from fixed SQM reference sites to correct traverse data

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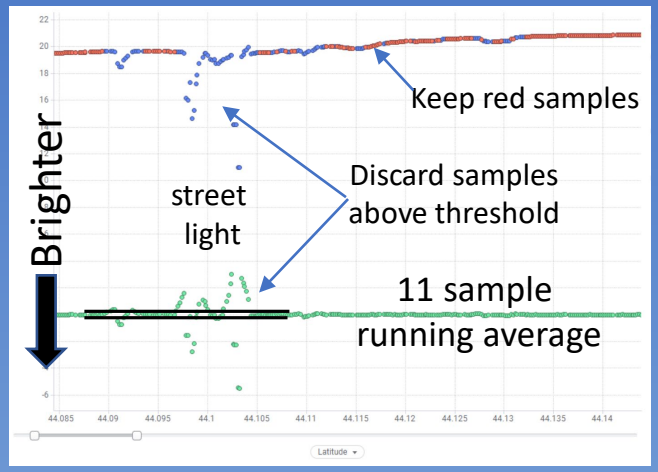
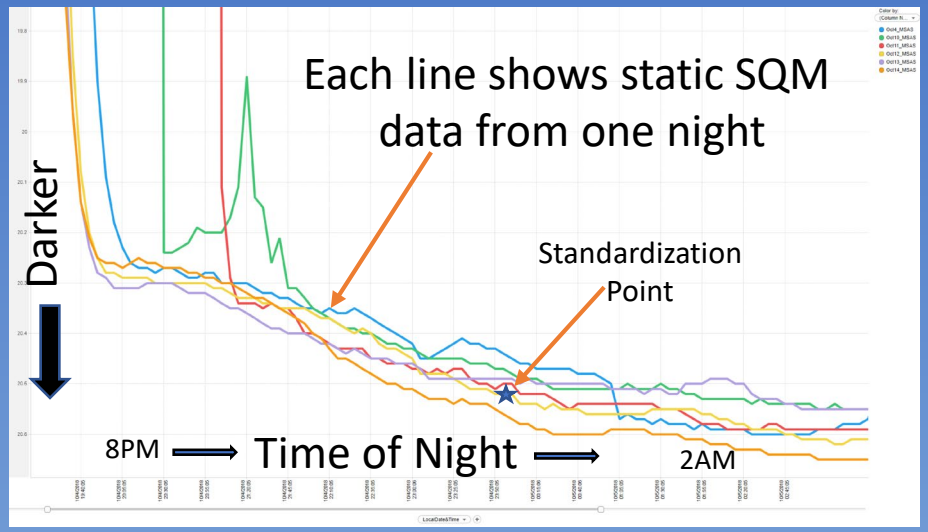
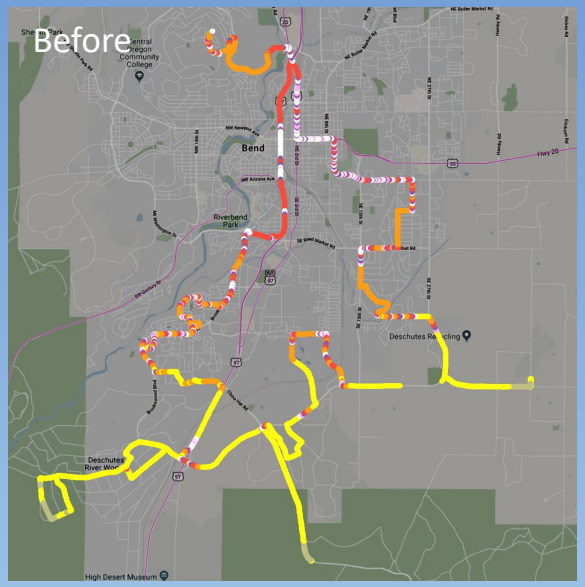
Method 2 - SQM zenith profiles from moving vehicle



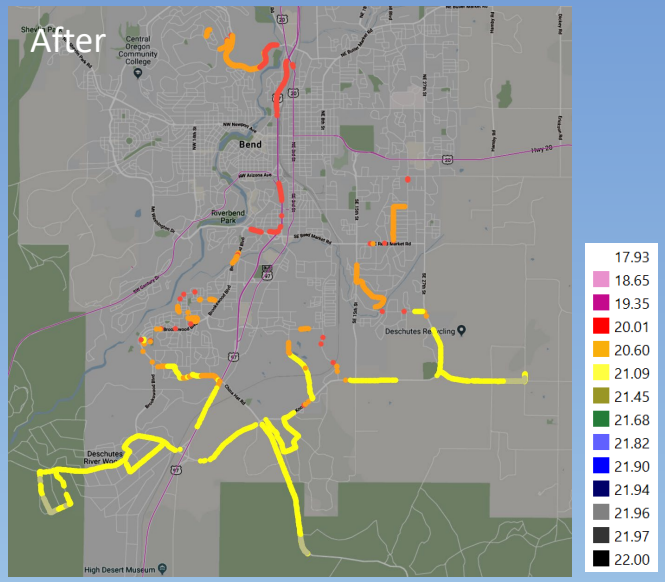
Eliminate data under street lights
Eliminate data if car speed < 5 mph



Adjust by +/- mobile SQM data to one time of one night



Artifact Correction



One night's survey – City of Bend and suburbs, Oct 14, 2018

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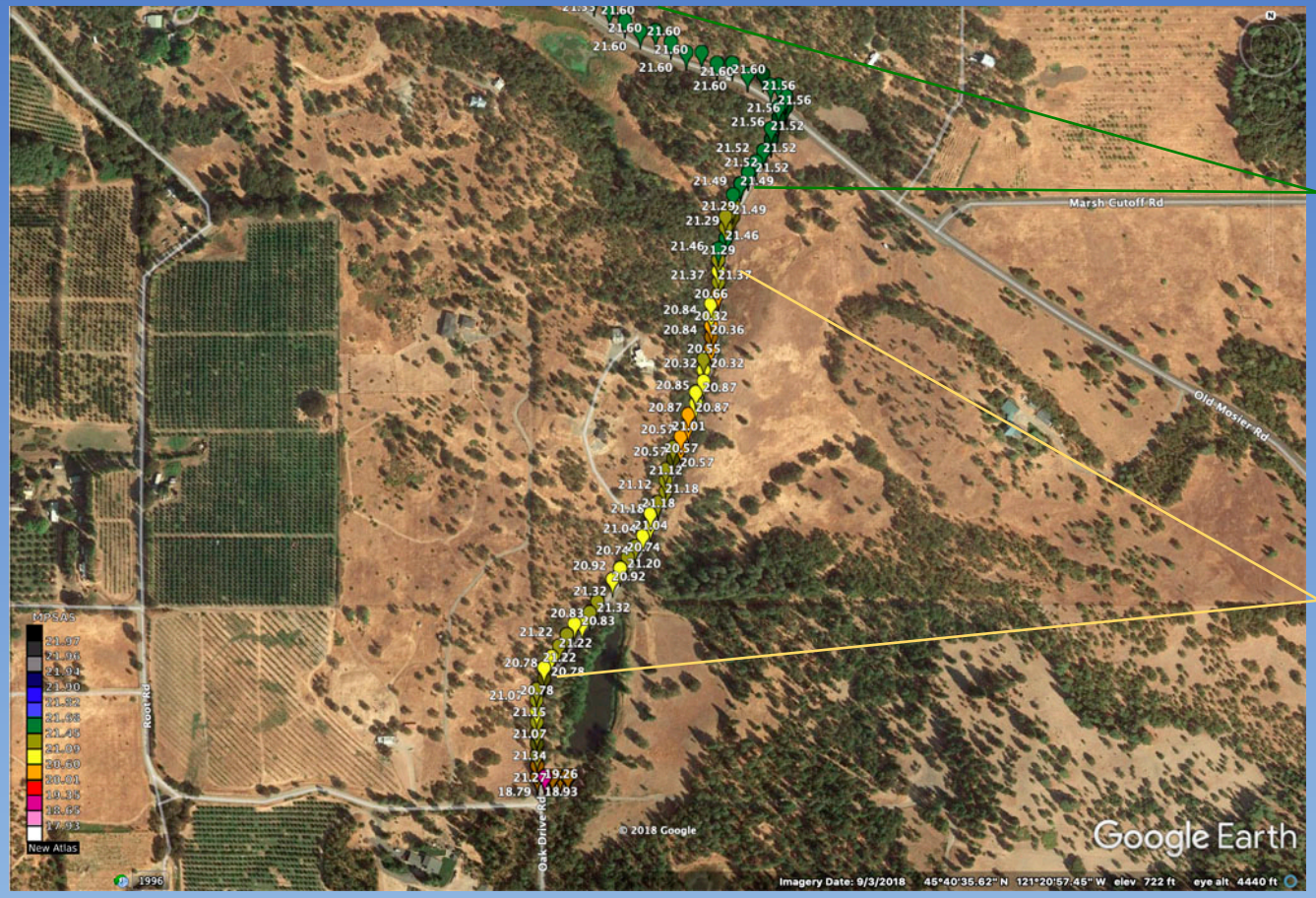
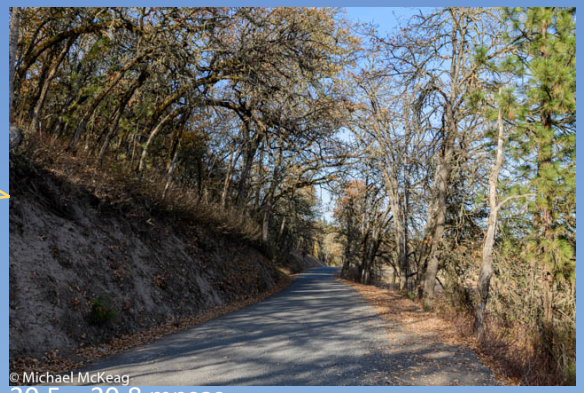
Method 2 - SQM zenith profiles from moving vehicle

Headlight scatter from landscape – overhanging trees



21.6 mpsas



20.5 – 20.8 mpsas

Wide 2-lane road vs. narrow gravel road under tree canopy; vehicle headlights low beam throughout.

Scout route in daylight - select and record location of suitable stops
During night -- Pull off and stop, turn off headlights
Make a series of measurements at that GPS location

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Method 3 – All-sky fisheye photography, SQM zenith measurement & SQM hemispheric sky brightness mapping

Area of Interest

- At a proposed dark sky place
- In a city and outskirts with lights encroaching?

Time Frame

- Several nights, a few measurement samples?
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- Directly overhead
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- Photos from airplane or drone?
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Method 3 –All-sky fisheye photography and SQM zenith equipment

McKeag residence, Mosier, OR

Page Springs CG,
Frenchglen, OR

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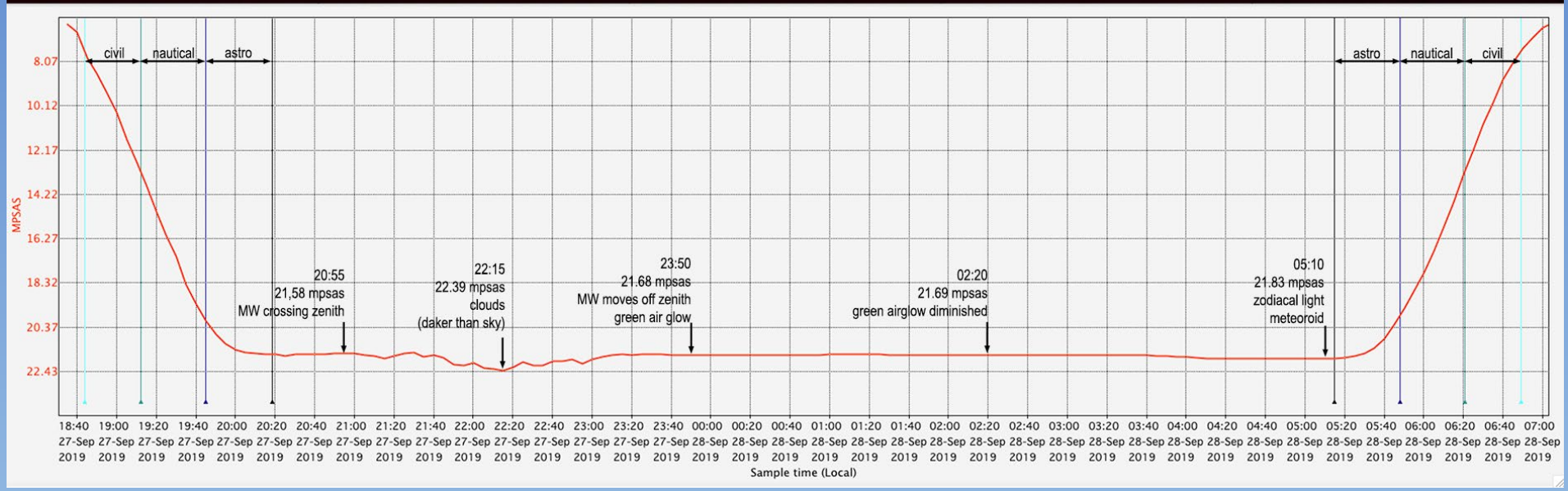
Method 3 –All-sky fisheye photography and SQM zenith data 27-28 Sep 2019, South Steens CG, Fenchglen, OR



Animation: interactive data browsing …

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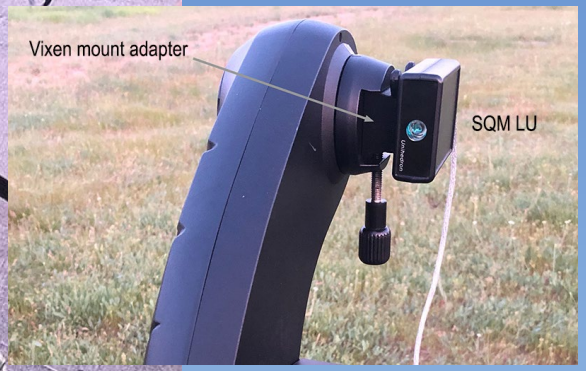
Method 3 – SQM hemispheric sky brightness mapping equipment



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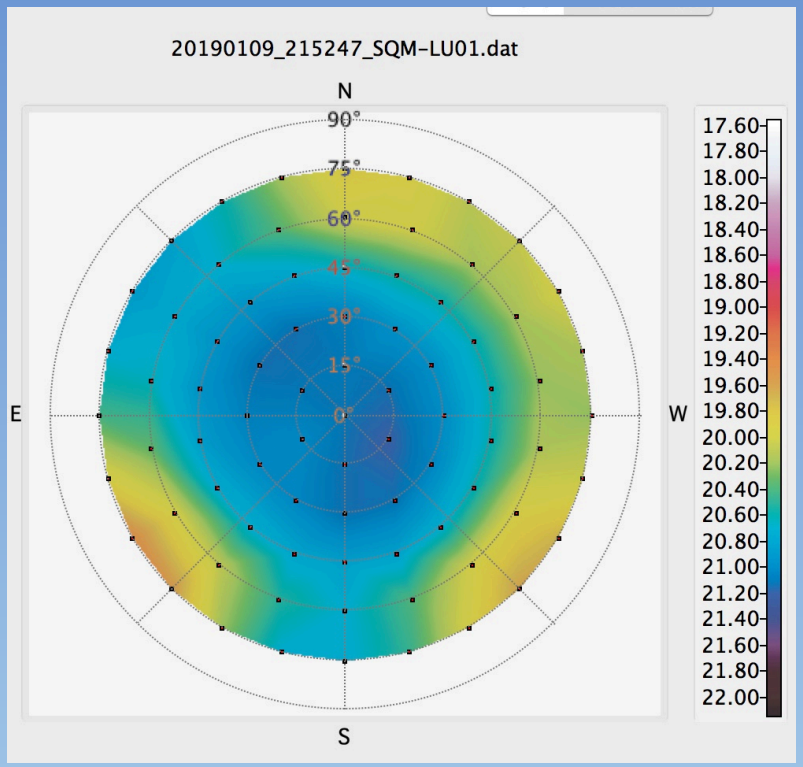
Method 3 – SQM hemispheric sky brightness mapping process

- Process controlled by Unihedron Device Manager (UDM) running on laptop
- SQM-LU measurements triggered and data read by UDM via USB
- Alt-Az mount pointing commanded by UDM via USB/serial through Celestron SynScan V4 hand controller
- Pointing pattern covers sky from zenith angle 0 – 75 deg.
- Custom pointing patterns easily defined by ASCII script
- Sky brightness map data polar plot produced using vector map module in UDM



Sky brightness plot example, dots mark pointing positions.

Map acquired 9 Jan 2019, at Borrego Mountain, Anza-Borrego Desert SP, CA. Light domes: N - Palm Springs, NW - Los Angeles, SW - San Diego, SE - Mexicali.

Map data acquisition takes about 17 minutes.

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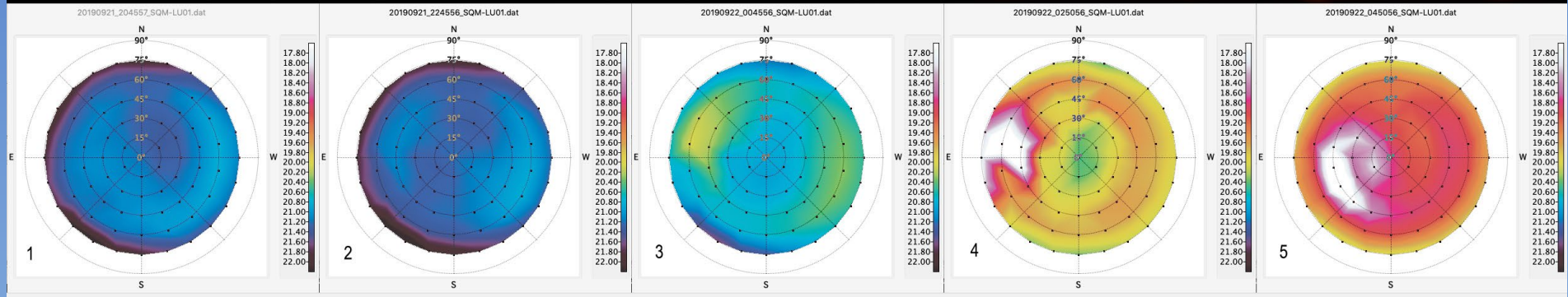
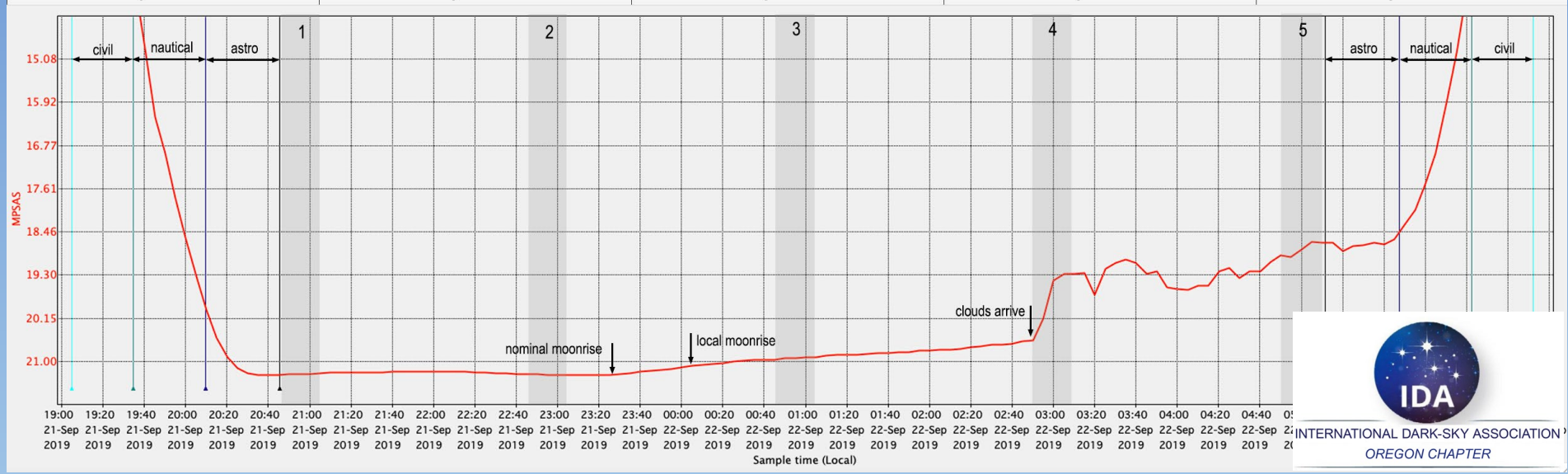
Method 3 – All-sky fisheye, SQM sky brightness map, SQM zenith, night of 21-22 Sep 2019, Mosier, OR.





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Method 4 -- Nighttime satellite images of the Earth

Area of Interest

- At a proposed dark sky place?
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- Published maps?
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- Qualitative all-sky imaging?
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- Photos from airplane or drone?
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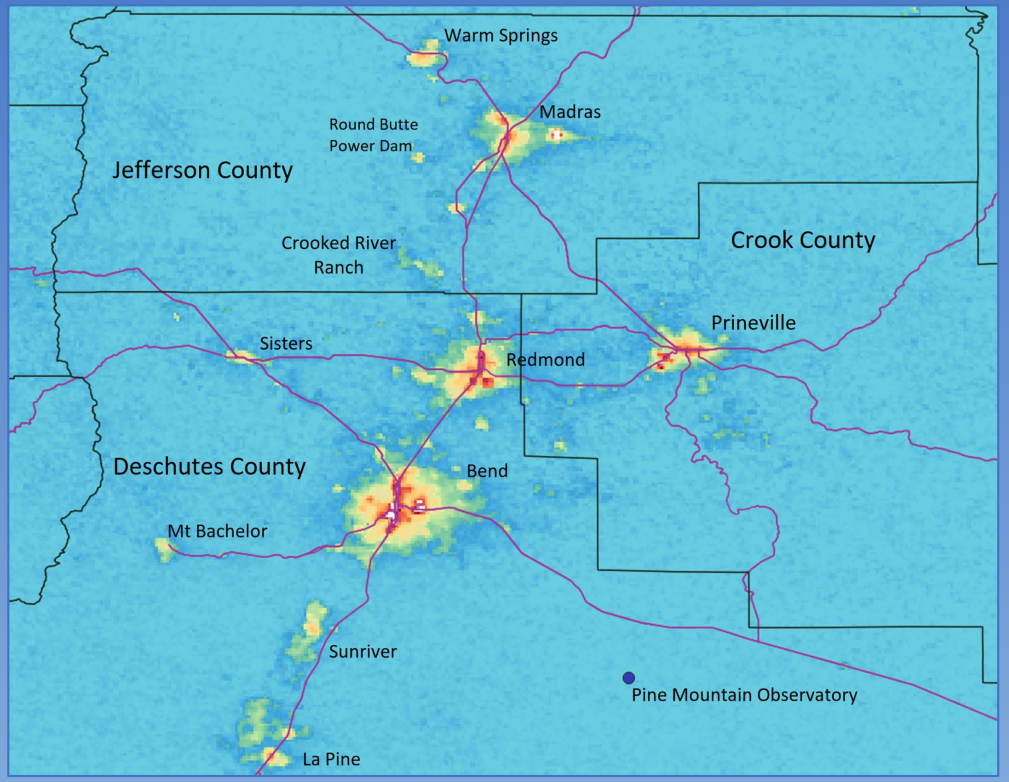
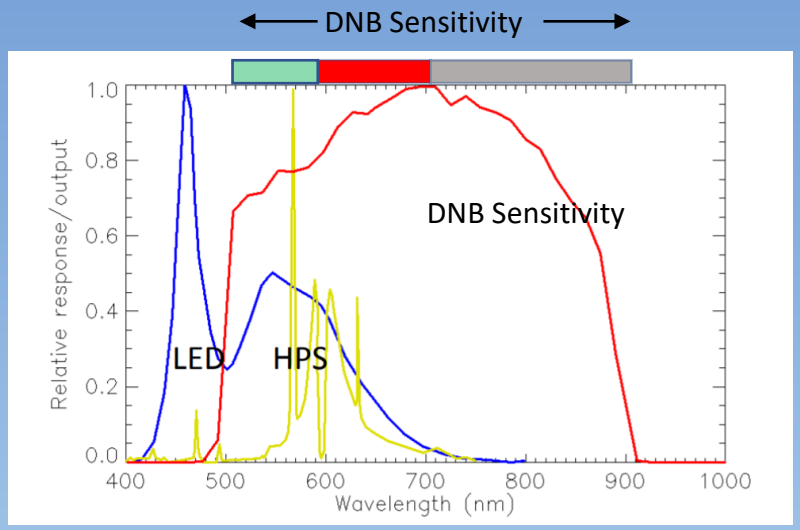
Method 4 -- Nighttime satellite images of the Earth

Central Oregon
VIIRS Day-Night Band (DNB)
1:30AM April 2018



- Detects upward directed light, not downward directed skyglow
- Monthly averaged nighttime images

- How do cities in Central Oregon compare in upward light trends to other cities in the western US?



Issues – VIIRS DNB:

- Sees Green, Red, Infrared light
- Does not see Blue light
- Large pixel size – 500m
- Few valid data points over time
  - Exclude stray light at high latitude in Summer
  - Exclude snow cover in Winter

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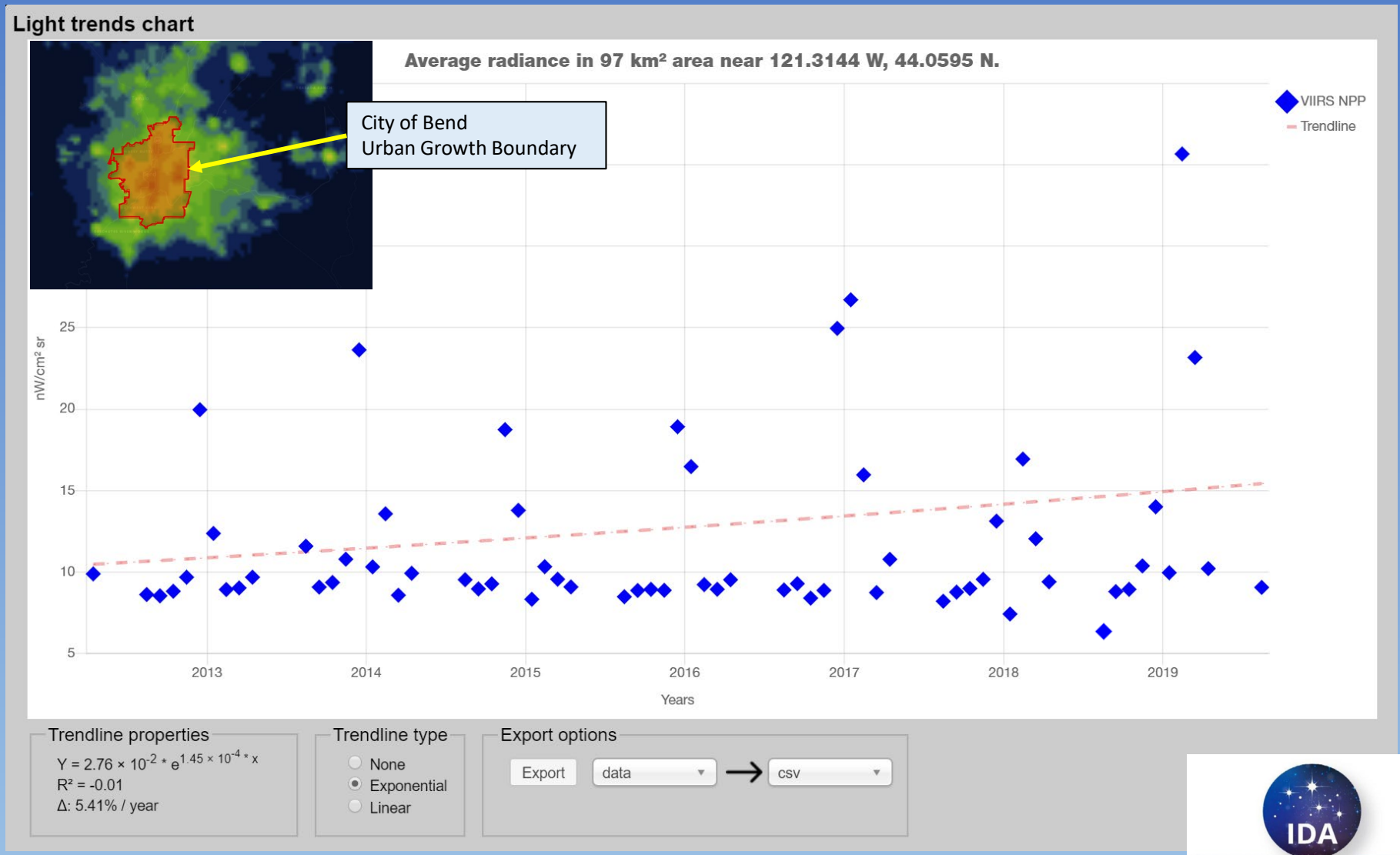
Method 4 -- Nighttime satellite images of the Earth

Radiance Light Trends – https://lighttrends.lightpollutionmap.info/



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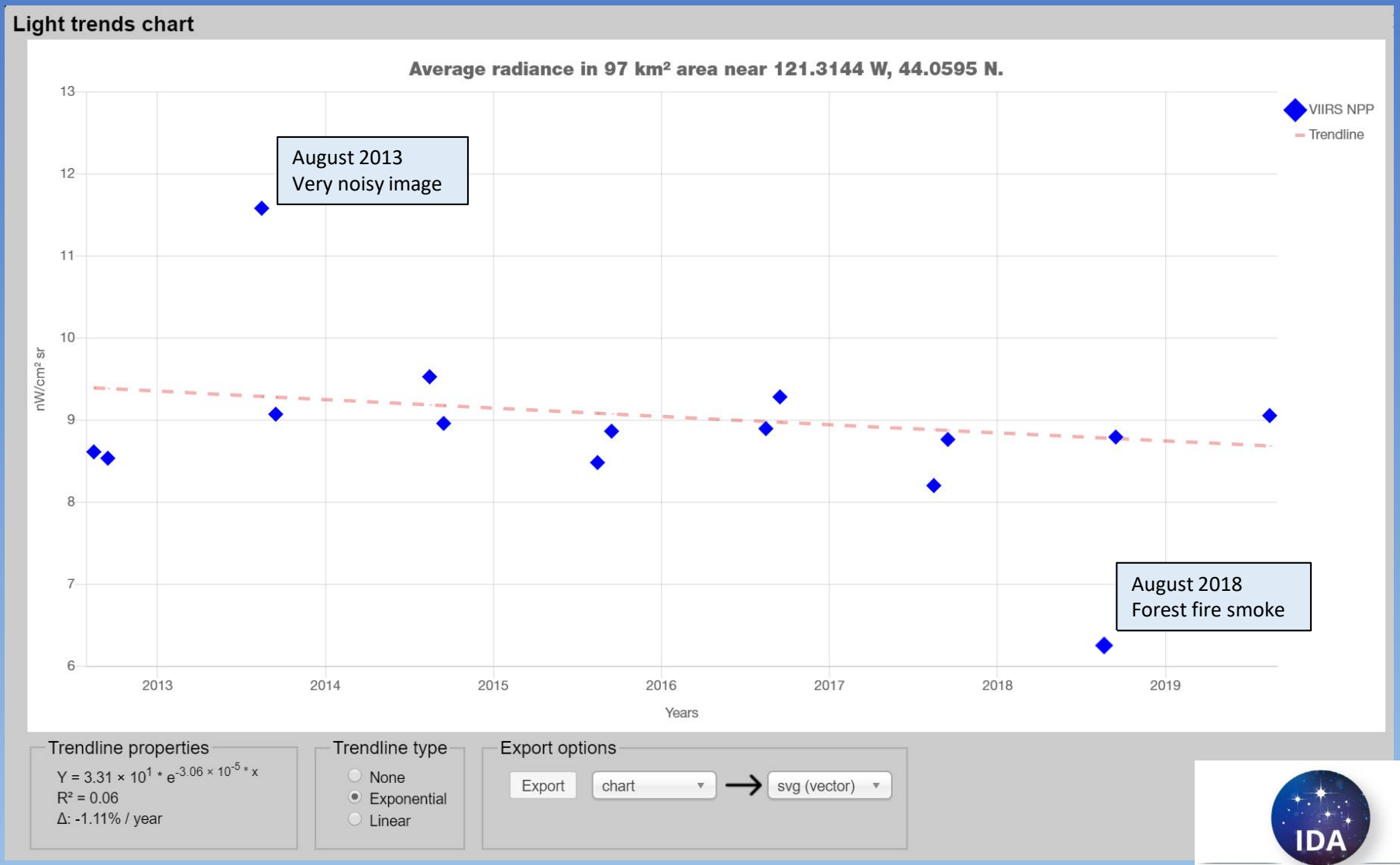

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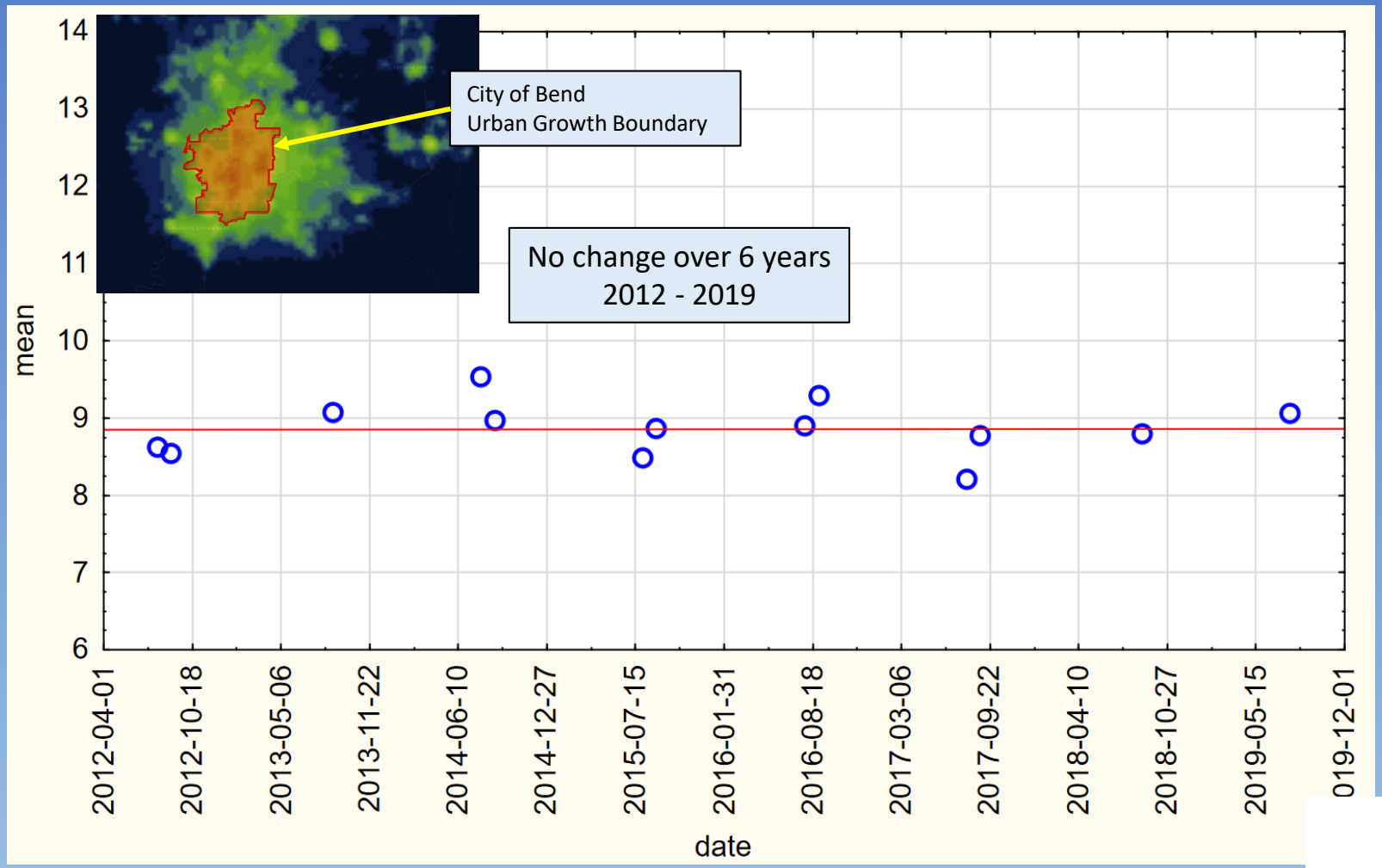

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Method 4 -- Nighttime satellite images of the Earth

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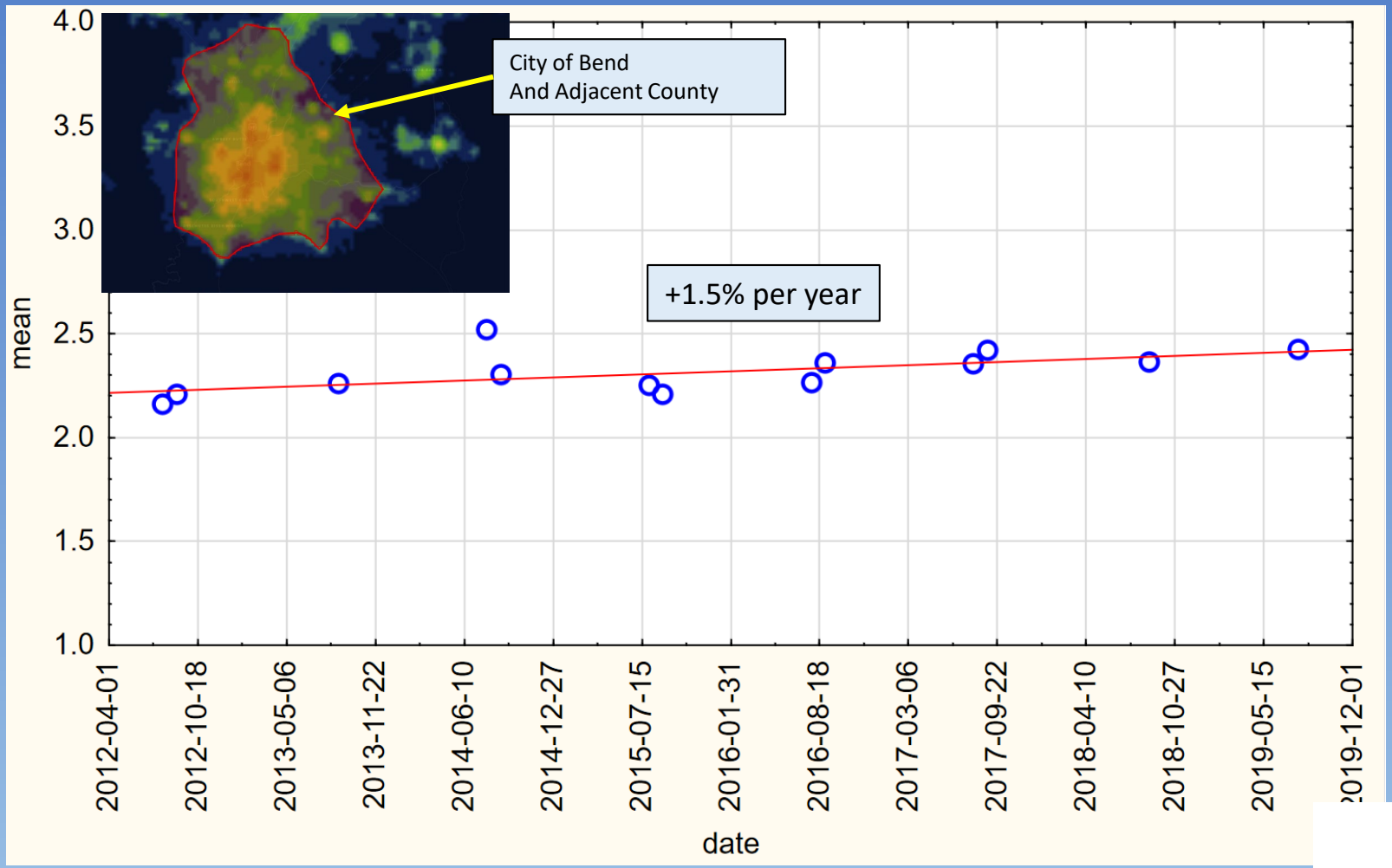

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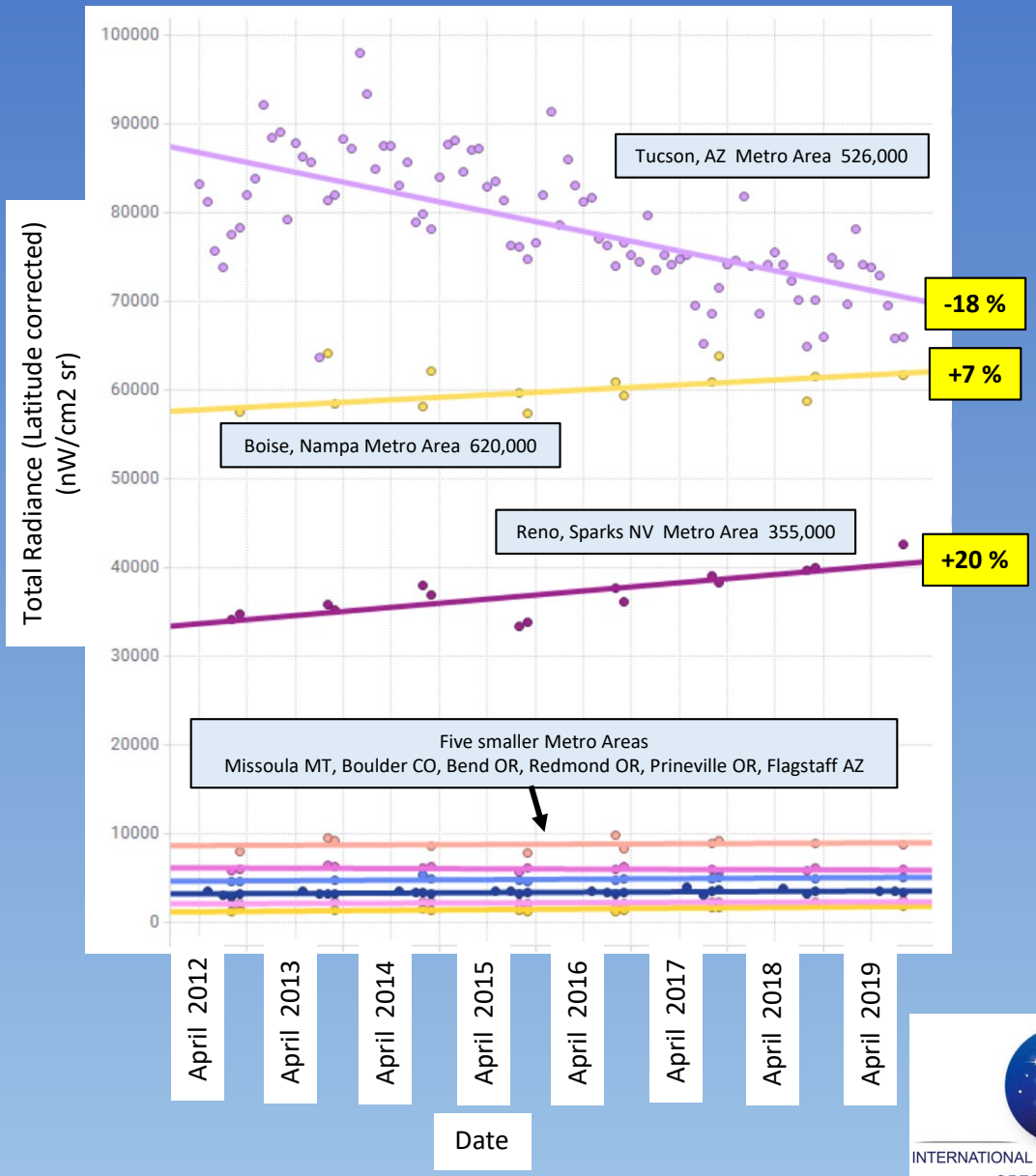
Method 4 -- Nighttime satellite images of the Earth

Nighttime Trends in Total Radiance of Several Metro Areas in the Western US

Trends:

- Tucson AZ trends down – streetlights to LED in 2017
- Boise & Nampa, Reno &Sparks NV up



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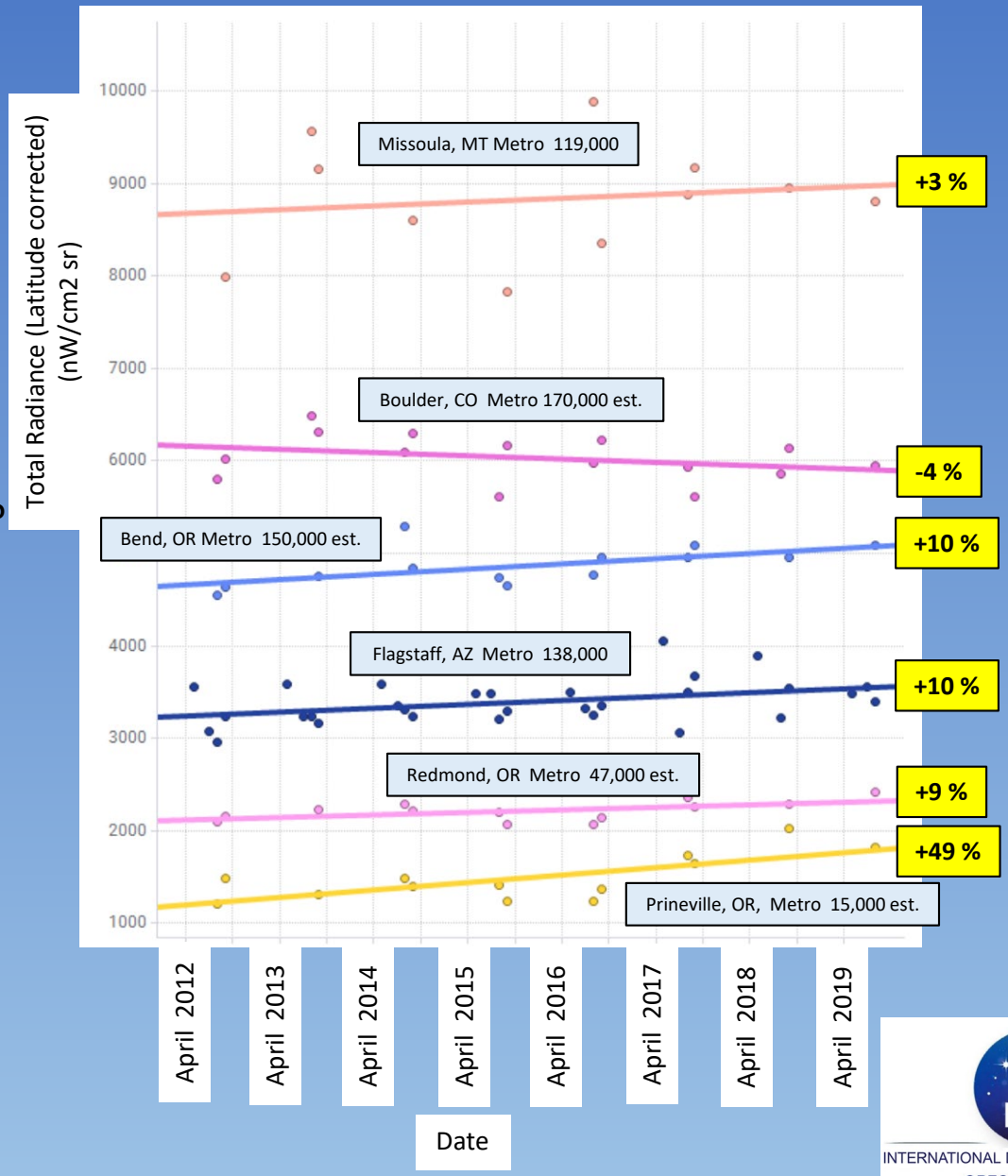
Method 4 -- Nighttime satellite images of the Earth

Nighttime Trends in Total Radiance of Several Metro Areas in the Western US

Trends in Metro Areas:

- Missoula, bright and up
- Boulder down
- Bend, Redmond, Flagstaff up
- Prineville way up –data centers?



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Conclusions
What answers did we find in Central Oregon?

- What's the current level and extent of light pollution?—

  The Fixed and Mobile SQM data show that the skyglow domes over each city in Central Oregon overlap and spread far into the high desert and Cascade Mountains
- Is the light pollution getting worse? –
  - We now have a baseline of Fixed SQM data
  - We need more data over several years
- Do we have candidate Dark Sky Areas? –
  - Yes, the Fixed and Mobile SQM data show that three areas under measurement have skies dark enough to merit IDA Dark Sky recognition
    - Pine Mountain Observatory -- Reserve
    - Prineville Reservoir State Park -- Park
    - Oregon Observatory at Sunriver -- Community
  - Hemispheric fisheye photos and hemispheric SQM data show that skyglow is visible on their horizons

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Conclusions
What answers did we find in Central Oregon?

- Can we accumulate information to help decision-makers on lighting ordinances in Central Oregon?
  - Yes, it's a work in progress
  - Fixed and Mobile SQM measurements at our most light-polluted measurement sites in Bend have led to increased recognition of local light pollution
- How do cities in Central Oregon compare in upward light trends to other cities in the western US?
  - Upward radiance from Central Oregon metro areas measured by VIIRS has increased by 10% since 2012
  - VIIRS inability to see Blue Light suggests the increase of upward visible light radiance in Central Oregon is actually larger
  - Tucson AZ and Boulder CO show a decrease in upward radiance measured by VIIRS in part due to switch from yellow sodium lights to white LED lights

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Conclusions
What have we learned about Light Pollution Measurement?

- Measurements under a variety of atmospheric/seasonal conditions are necessary to characterize the night sky at a site
- Contemporaneous all-sky fisheye photography combined with SQM ZSB is more informative than either data type alone.
- A “field guide” to common ZSB trend patterns based on contemporaneous all-sky imagery will be helpful
- Mobile SQM measurements are more difficult to acquire and process compared to fixed site SQM – artifacts, reduce data to a standard time, driving at night a safety issue
- Use of GIS offers increased flexibility in data processing and display, and adds to complexity and skill level required
- The VIIRS nighttime data have large a pixel size and do not pick up blue light, which greatly limits their usefulness in tracking lighting trends

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Tibco's Spotfire software employed under the
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Radiance Light Trends: www.lighttrends.lightpollutionmap.info

VIIRS Image and Data processing by NOAA's National Geophysical Data Center

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Extra Slides

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Future Work

- Calibrated camera/lens for all-sky, fisheye photography
- Fixed, high resolution all-sky cameras at several SQM sites
- Expand SQM network to Oregon/Washington Columbia River Gorge
- Regional lighting inventory – hilltop & aerial photography, drones?
- Tracking uplight by satellite – need histograms of radiance, account for population and growth

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The tools and methods we employ are commercially available and readily applied

- Hardware
  - Sky Quality Meters
  - Cameras with fish eye lens on tripod
  - Alt-Azimuth astronomy mount
  - Laptop
- Software
  - Unihedron (UDM) software for downloading SQM data
  - Excel, Notepad, Cygwin (Linux tools)
  - Google Earth
  - QGIS – open source GIS for map data analysis and display
  - Statistica – for statistical summary
  - Spotfire – for data exploration and plotting

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Avian issues during skyglow characterization!

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Method 2A - SQM zenith profile by stop & measure

Landscapes not suitable for continuous travel zenith profiling:

- Frequent overhead lights
- Frequent approaching or following vehicles
- Headlight backscatter from cliffs, structures, etc.
- Headlight backscatter from surrounding and overhanging trees

Scout route in daylight selecting and recording suitable stops (GPS waypoints):

- Unobstructed view of sky overhead
- No nearby artificial lights that will affect Zenith measurements
- Safe location to pull off and park off traveled roadway

Stop & measure procedure:

- SQM, GPS & laptop configured as for Method 2
- Pull off and stop, turn off lights
- In “measure continuous mode” make a series of measurements
- Turn on lights, and continue along route
- Geolocated zenith measurements for each stop will be recorded in individual DAT files.

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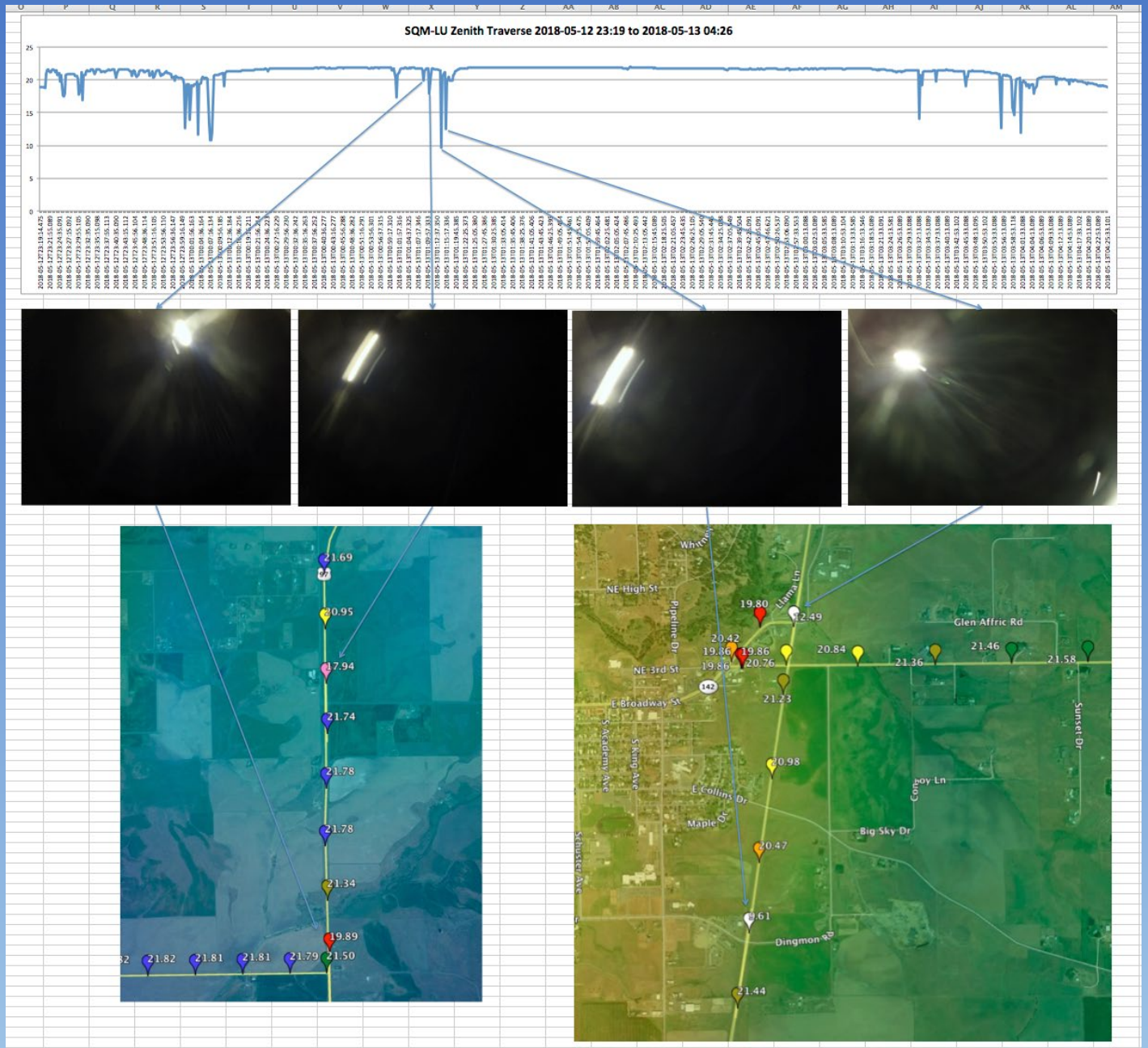
Overhead streetlight effect on Mobile SQM



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Portland's skyglow is visible from Bend

View northwest from
Awbrey Butte
January 31, 2019 2:39AM

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Sky Quality Meter records brightness in units of Magnitudes per square arc second

An SQM reading of 19.0 — typical for a medium-dark suburb — means that the sky glows as though the light of one 19.0-magnitude star were smeared out across each square arcsecond of sky.

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Relationship between Bortle Scale and SQM data

https://en.wikipedia.org/wiki/Bortle_scale

The **Bortle scale** is a nine-level numeric scale that measures the night sky's brightness of a particular location. It quantifies the astronomical observability of celestial objects and the interference caused by light pollution.

Class	Title	NELM	Approx. SQM[3] mag/arcsec²	Description
1	Excellent dark-sky site	7.6–8.0	21.7–22.0	• the zodiacal light is visible and colorful • the gegenschein is visible • the zodiacal band is visible • airglow is readily visible • the Scorpius and Sagittarius regions of the Milky Way cast obvious shadows • many constellations, particularly fainter ones, are barely recognizable due to the large number of stars
2	Typical truly dark site	7.1–7.5	21.5–21.7	• clouds are only visible as dark holes against the sky • surroundings are barely visible silhouetted against the sky • the summer Milky Way is highly structured
3	Rural sky	6.6–7.0	21.3–21.5	• some light pollution evident at the horizon • clouds are illuminated near the horizon, dark overhead • nearer surroundings are vaguely visible • the summer Milky Way still appears complex
4	Rural/suburban transition	6.1–6.5	20.4–21.3	• light pollution domes visible in several directions • clouds are illuminated in the directions of the light sources, dark overhead • surroundings are clearly visible, even at a distance • the Milky Way well above the horizon is still impressive, but lacks detail
5	Suburban sky	5.6–6.0	19.1–20.4	• clouds are noticeably brighter than the sky • the Milky Way is very weak or invisible near the horizon, and looks washed out overhead
6	Bright suburban sky	5.1–5.5	18.0–19.1	• the zodiacal light is invisible • light pollution makes the sky within 35° of the horizon glow grayish white • clouds anywhere in the sky appear fairly bright • even high clouds (cirrus) appear brighter than the sky background • surroundings are easily visible • the Milky Way is only visible near the zenith
7	Suburban/urban transition	4.6–5.0		• light pollution makes the entire sky light gray • strong light sources are evident in all directions • clouds are brightly lit • the Milky Way is invisible • when it is full moon in a dark location the sky appears like this, but with the difference that the sky appears blue • limiting magnitude with 12.5" reflector is 14
8	City sky	4.1–4.5	<18.0	• the sky is light gray or orange – one can easily read • stars forming familiar constellation patterns may be weak or invisible
9	Inner-city sky	4.0		• The sky is brilliantly lit • many stars forming constellations are invisible and many fainter constellations are invisible • the only objects to observe are the Moon, the planets, and a few of the brightest star clusters

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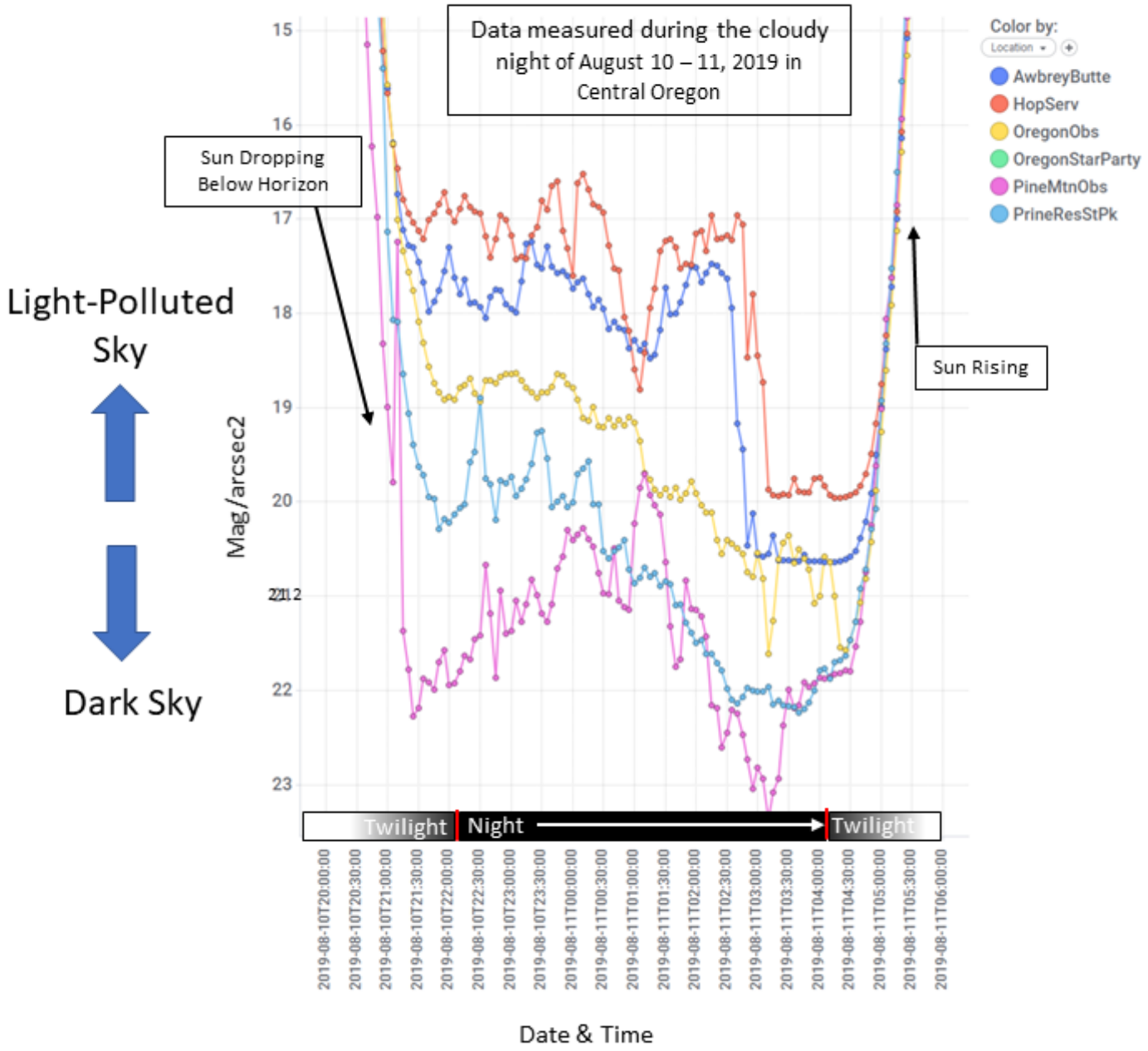
Method 1 – Fixed Location SQM Data - A Cloudy Night



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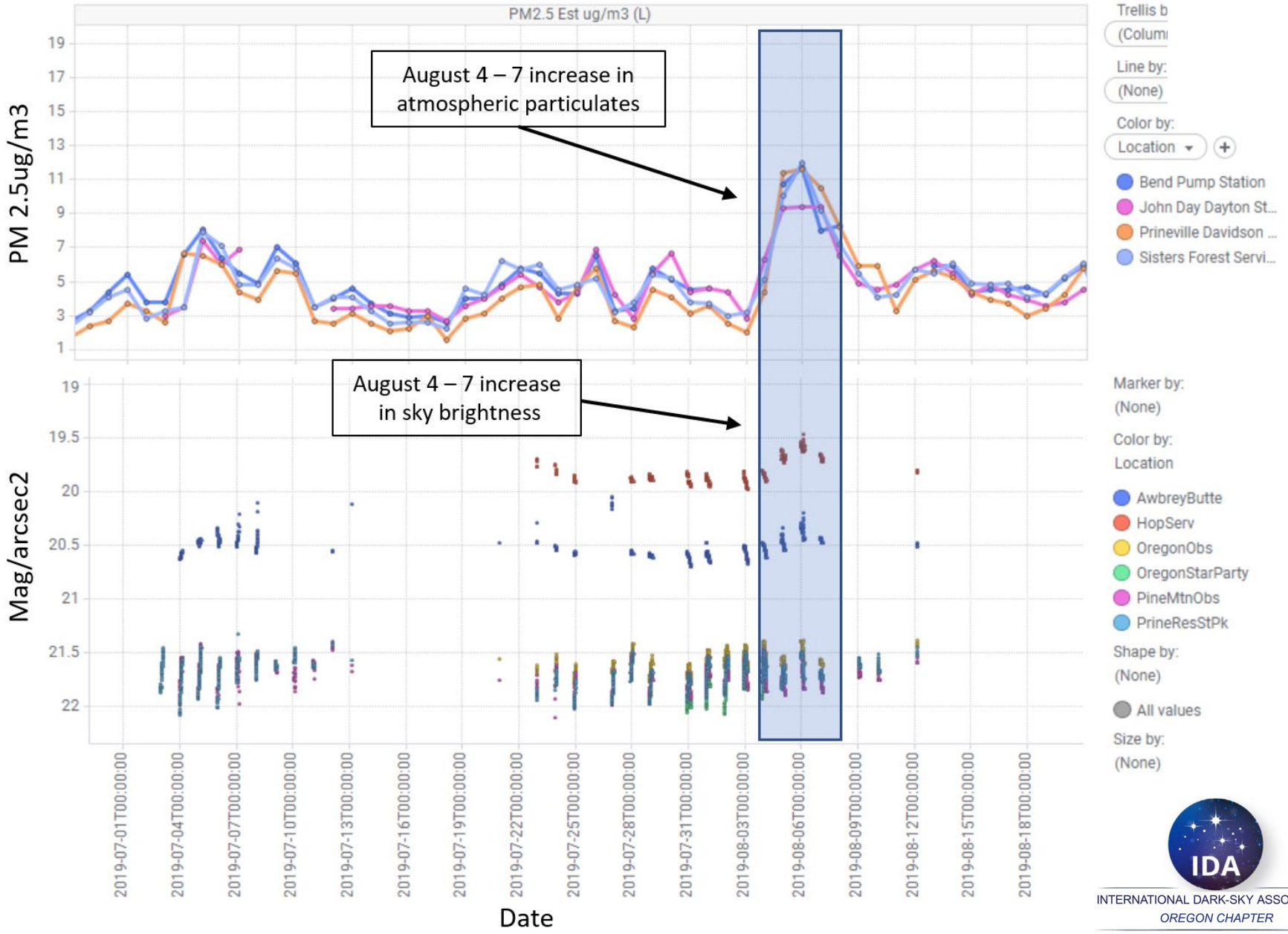
Increase in sky brightness over several days at two light-polluted sites is associated with increase in aerosol particulates



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