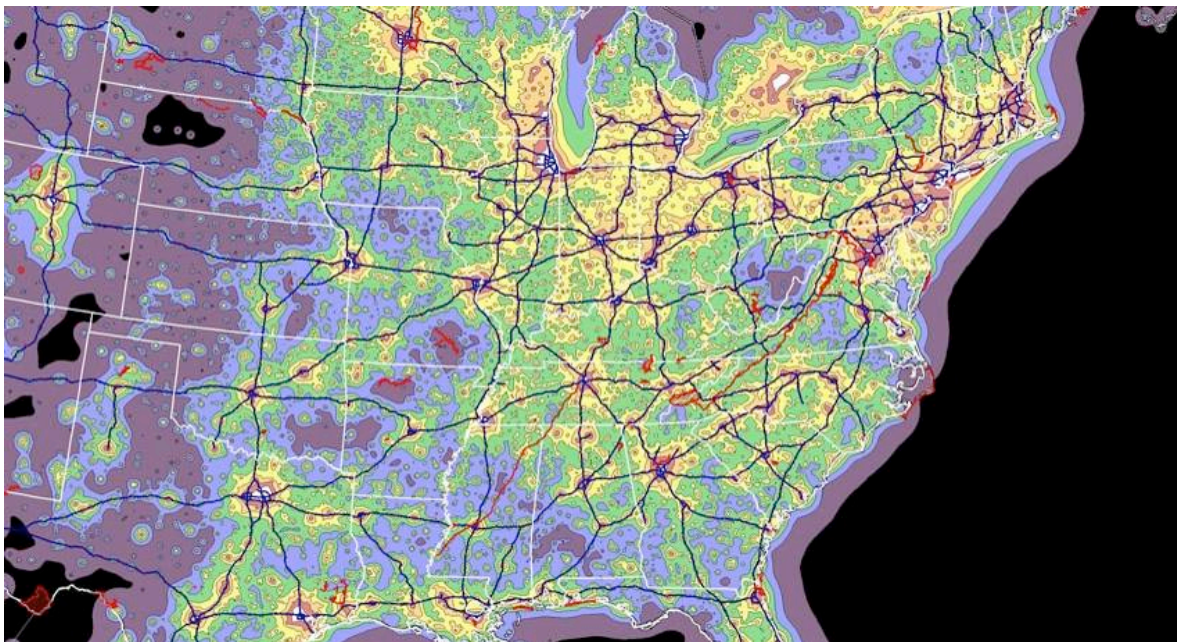




Night Sky Team site visit to Cape Hatteras National Seashore

Kate Magargal – National Park Service Night Sky Program

Based on satellite generated models of light pollution (Cinzano et. al, 2000 – see picture below), the Night Sky Team (NST) estimated Cape Hatteras National Seashore as one of only a handful of sites in the eastern U.S. with a nearly natural regimen of light and dark, where lighting patterns are governed primarily by celestial sources. This is primarily due to the location of Cape Hatteras National Seashore far from any large urban areas, often the largest contributors to light pollution. Upon visiting Cape Hatteras National Seashore in November 2007, the NST recorded some preliminary measurements of night sky quality from three sites along the island. These measurements confirm Cape Hatteras National Seashore as having significant night sky quality as compared to most other NPS units east of the Mississippi River. The measurements also show light pollution sources beyond the park boundary highlighting the need to be conscious of this precious and easily damaged resource.



Picture created by Cinzano, et al. showing the presence of light pollution in parts of the US. Warmer colors represent higher light levels. National Parks are outlined in red. Note Cape Hatteras' location near the edge of the modeled influence of light pollution.

The National Park Service measures sky brightness using images of the night sky taken with a CCD camera (scientific grade digital camera). Stars in the pictures with a known magnitude (a measure of stellar brightness) are used as an index to extract the ambient brightness of the nighttime sky (see Appendix A). This data does not effectively capture light from transient or direct sources, such as vehicle headlights or nearby streetlights directly visible from the observing site. The NST is currently developing a separate system to measure the amount of biologically significant light (with the potential to alter species' behavior) from incidental sources. Presently, the timeline and funding of this system is uncertain. The current CCD camera system is optimized for measuring the night sky as a human would see it, and is intended as a tool for protecting night sky scenery. Stable and clear conditions are necessary for proper operation.

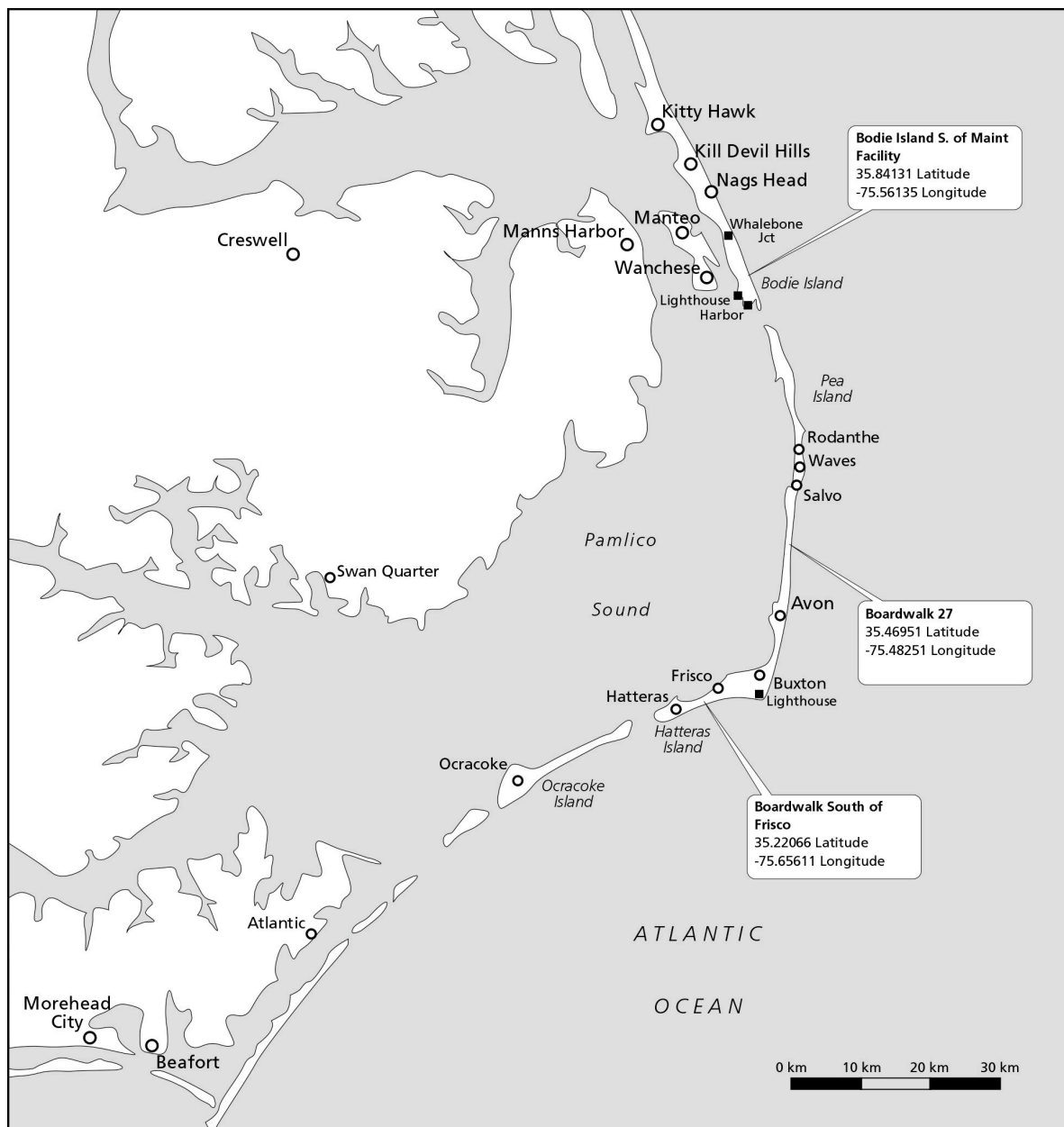
Atmospheric conditions play a role in how light travels through the sky. In dry desert environments, common in the southwestern U.S., light can travel for hundreds of miles from the source, causing extensive lighting influence from cities and towns. In conditions prevalent in the southeast, higher humidity and particulate levels dampen the transmission of light from distant sources. However, sky glow, the scattering of light due to photons bouncing around in the atmosphere, is increased near the source, brightening the sky immediately surrounding light sources. Due to the strong influence of moisture and atmospheric clarity upon light pollution, we can seldom make a full assessment in a single site visit. Night sky quality data was recorded from three sites (see map below) during two nights in November 2007. The nights were characterized by high humidity and partly clear skies. Additional data collection periods, planned to take place over the next few years, will yield a better baseline assessment. Table 1 is a summary of the preliminary data.

Date	Location	Bortle Class	Limiting Magnitude	Zenith Sky Brightness (magnitudes/s q arc second)	Whole Sky Brightness (magnitudes)	Sky Above 20° Altitude (magnitudes)
11-13-07	Board Walk South of Frisco	4	5.6	21.50	-7.69	-6.9
11-15-07	Boardwalk 27	3	NA	21.69	-6.63	-6.63
11-15-07	Bodie Island South of Maintenance Facility	4 – 5	NA	21.38	-8.13	-7.17
	Natural Baseline	1 – 2	7.0 - 7.5	22.00-22.20	-6.8 - 7	6.2-6.4

Table 1: Summary of data*. Date and Location cells describe the time and place of observations. The Bortle Class** is a scale developed to estimate night sky quality based on a series of qualitative measures. The scale ranges from 1, a pristine sky, to 9, an urban light polluted sky. Limiting Magnitude refers to the dimmest star that can be seen in the darkest part of the sky with averted vision. It is in units of stellar magnitude. The Zenith Sky Brightness is the brightness of the sky directly overhead. Whole Sky Brightness is the median value of the brightness of the entire visible sky. The last row of the table shows the theoretical natural conditions. The astronomical magnitude scale is inverted, with negative numbers indicating brighter light flux.

*For more detailed explanations see Appendix B or the lightscares website, <http://www.nature.nps.gov/air/lightscapes/monitorData/dataPageExplain.cfm>

**For a detailed description of the steps in the Bortle Scale, visit http://skyandtelescope.com/resources/darksky/article_81_1.asp



Map showing the locations of the three data collection sites visited in November 2007.

These measurements show that light pollution from local sources varies along the Outer Banks depending on the proximity of the site to collective light sources such as towns and facilities. Sky brightness ranges from approaching a natural level of darkness to significantly light polluted. In some areas, this light pollution has the potential to pose a variety of threats to the ecological health of the coastal environment. Coastal wildlife is generally sensitive to light pollution, particularly sea turtles and migratory birds such as the federally listed Loggerhead Turtle and Piping Plover for which Cape Hatteras National Seashore contains important habitat. Light pollution has been identified elsewhere as a factor contributing to the decline of these populations as documented by an increasing body of scientific literature. Light pollution affects more than wildlife. Dark places are also important to humans, as evidenced by the overwhelming popularity of stargazing programs in national parks. The nation's public is increasingly seeking a view of the cosmos from places already set aside by Congress to protect natural systems and views, such as Cape Hatteras National Seashore.

The National Park Service, local residents, property owners and businesses have a unique opportunity to help maintain and further restore one of the last remaining dark areas in the eastern part of the

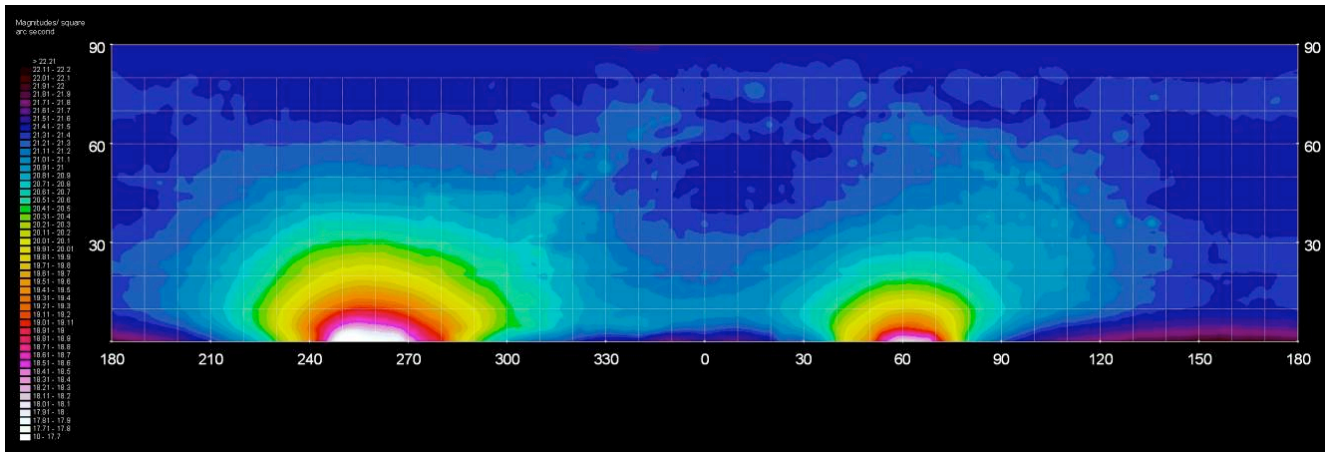
United States. Retrofitting or swapping existing luminaires (light fixtures) for turtle friendly and night sky friendly luminaires will greatly improve night sky quality, ecosystem health, the safety and security functions of community lighting, and reduce long term costs— economic and environmental— associated with outdoor lighting. Cape Hatteras National Seashore will soon begin the process of documenting its luminaires and developing turtle friendly guidelines to govern the use of light on federal lands. However, the restoration of optimal levels of natural darkness cannot be attained without the help of park neighbors. The NST is available to provide technical assistance to communities interested in improving outdoor lighting. Efforts toward night sky friendly lighting already exist along the outer banks (i.e. the Nags Head lighting ordinance), and there are an increasing number of examples nationwide of parks and communities in partnerships to improve the quality of our nighttime environment.

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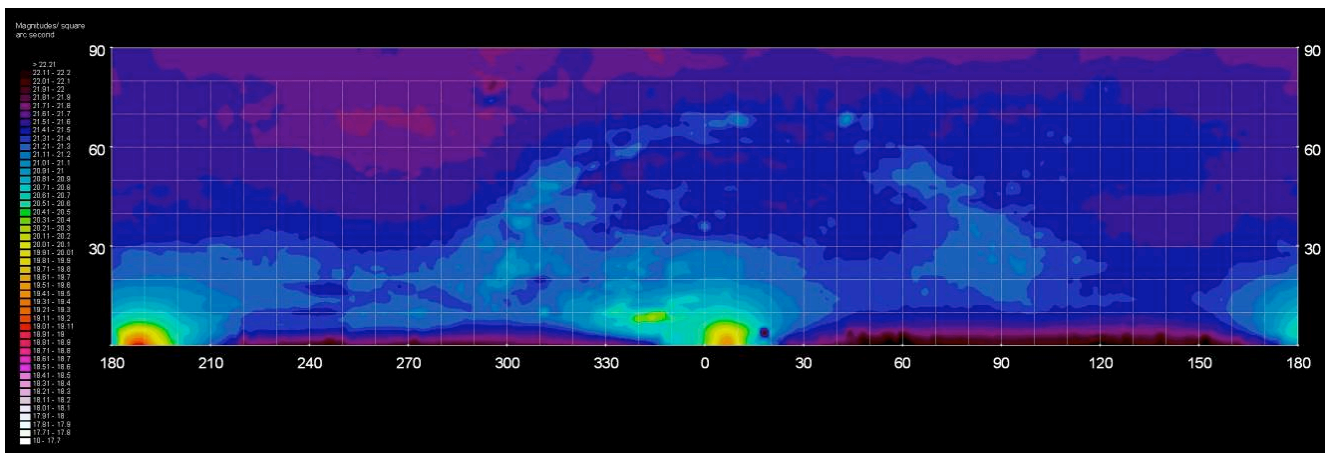
cc: Chad Moore
moore@cira.colostate.edu

Appendix A: False Color Mosaics

Below are three false color maps of light from sites within Cape Hatteras National Seashore. The entire sky is shown using an altitude (y-axis) and azimuth (x-axis) scale. Warmer colors (towards the bottom of the legend on the left) represent brighter areas, while cooler colors (towards the top of the legend) represent darker areas. Large natural light features can be seen, such as the Milky Way arching across both pictures, in addition to the dominant artificial light sources.

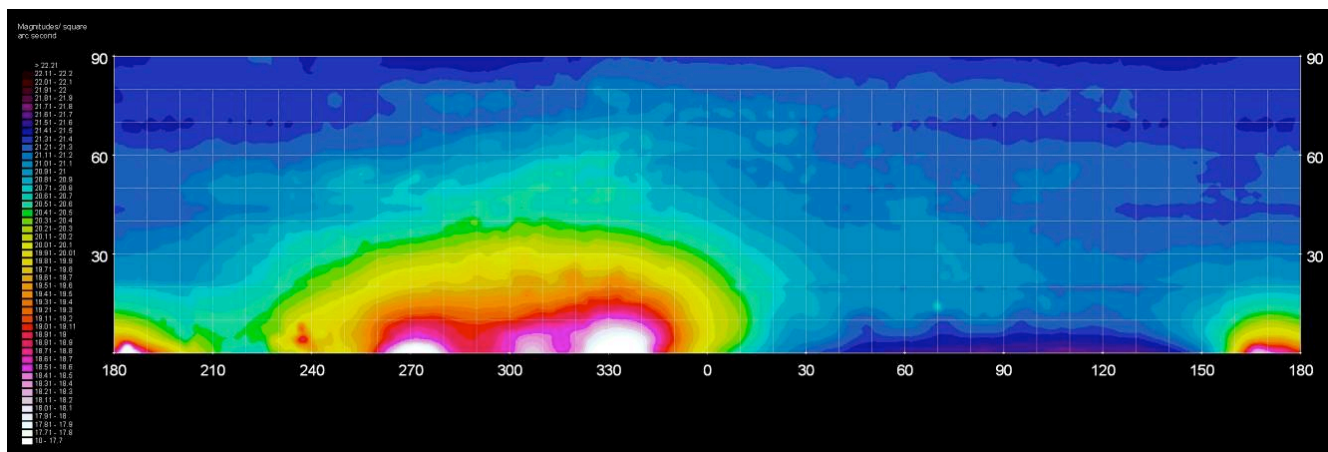


This picture was compiled from images captured on a boardwalk between Frisco and Hatteras. Frisco lies at about 60° azimuth and Hatteras at about 260° azimuth.



This picture was compiled from images captured on a boardwalk between Salvo and Avon. The combined light of Rodanthe, Salvo and Waves can be seen at about 6° and Avon at 191°. Also note the presence of a few clouds reflecting the town lights at about 345°.

0066477



This picture was compiled from images captured on Bodie Island, just south of the maintenance facility. A number of light domes are evident in this image, including the combined light from Harbor, Rodanthe and Salvo between 165° - 168°, the lighthouse at 184°, Wanchese at 267°, and the combined light from Manteo, Kill Devil Hills, Nags Head, and Kitty Hawk between 304° - 333°. A considerable amount of light scattering occurs in this picture due to high humidity.

Appendix B: Complete Data Summary and Explanation

National Park Service Night Sky Team

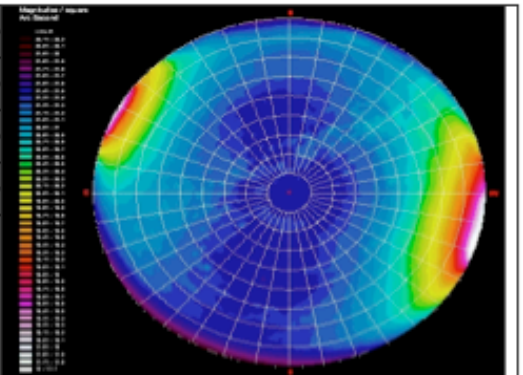
Night Sky Quality Monitoring Report



Report date: 12/3/07 by: K Magargal

PARK:	Cape Hatteras National Seashore	EQUIPMENT:	IMG 2, 50mm f/2, 6084
SITE NAME:	Board South of Frisco	OBSERVERS:	K Magargal, C Moore
LONGITUDE:	-75.65611	AIR TEMP ("F):	60
LATITUDE:	35.22066	REL HUMID (%):	70
ELEVATION (m):	3	WIND SP (mph):	6
DATE (UT):	November 13, 2007	CCD TEMP ("C):	-20
TIME START (UT):	4:21:09	EXP (seconds):	8
DATA QUALITY:	Good	BORTLE CLASS:	4
		ZLM:	5.6

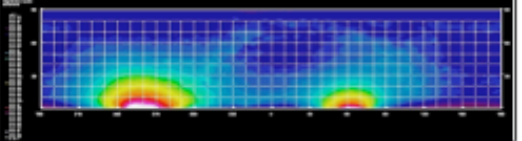
NARRATIVE: Site is located between Frisco and Hatteras, near highway 12, however headlights were excluded from images. A hazy night, but haze evenly distributed. Extinction high due to haze/humidity. On a less humid night, this site may be brighter. Overhead a good amount of detail in Milky Way detectable. ZLM 5.6 in Perseus. SQM 21.31. Thin clouds began to approach during second set of images.



SKY BRIGHTNESS DATA

LIGHT DOME DATA

Data Set Number	Time (UT)	Extinction coefficient (mag/air-mass)	Std Err Y Extinction Stars (mags)	Zenith (mag/sq arc-sec)	Whole Sky (mags)	Sky Above 20° Altitude (mags)	Brightest (mag/sq arc-sec)	Darkest (mag/sq arc-sec)	Link to Sky Maps	City	Distance (km)	Azimuth	1st Data Set Brightness (mags)
1st Start	4:21:09			21.50					PAN	Frisco	3	57.1	-4.42
End	4:37:44	0.307	0.044	21.51	-7.69	-6.90	17.53	21.54	HEMI	Hatteras	3	267.2	-5.98
2nd Start	4:41:20			21.49					PAN				
End	4:57:56	0.329	0.041	21.44	-7.72	-6.90	17.44	21.52	HEMI				
3rd Start													
End													
4th Start										Total			-6.22
End													
5th Start													
End													
6th Start													
End													



National Park Service Night Sky Team

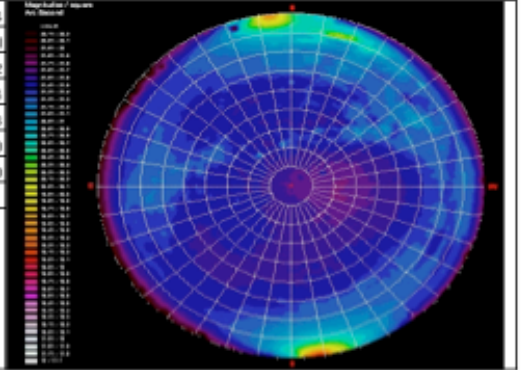


Night Sky Quality Monitoring Report

Report date: 11/20/07 by: K. Magargal

PARK:	Cape Hatteras National Seashore	EQUIPMENT:	IMG 2, 50mm f/2, 6084
SITE NAME:	Boardwalk 27	OBSERVERS:	K Magargal
LONGITUDE:	-75.48251	AIR TEMP (°F):	62
LATITUDE:	35.46951	REL HUMID (%):	84
ELEVATION (m):	3	WIND SP (mph):	3
DATE (UT):	November 15, 2007	CCD TEMP (°C):	-20
TIME START (UT):	3:08:52	EXP (seconds):	10
DATA QUALITY:	good	BORTLE CLASS:	3 ZLM: NA

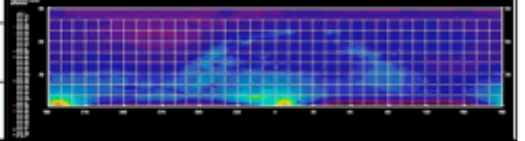
NARRATIVE: A very humid night. Some thin clouds barely detectable to the north and west (no light reflecting off clouds). Some Milky Way structure seen, but with a gap here and there in the band, probably more due to extinction than light pollution. On a less humid night, this spot may be significantly brighter. Location is only a few dozen feet away from the ocean, where extinction is visually observed to increase (eastward). A sign and clouds are altering the collective light dome of Rodanthe/Salvo/Waves.



SKY BRIGHTNESS DATA

LIGHT DOME DATA

Data Set Number	Time (UT)	Extinction coefficient (mag/air-mass)	Std Err Y Extinction Stars (mags)	Zenith (mag/sq arc-sec)	Whole Sky (mags)	Sky Above 20° Altitude (mags)	Brightest (mag/sq arc-sec)	Darkest (mag/sq arc-sec)	Link to Sky Maps	City	Distance (km)	Azimuth	1st Data Set Brightness (mags)
1st Start	3:08:52			21.69					PAN	Rodanthe	14	5.3	
End	3:27:00	0.293	0.044	21.72	-7.18	-6.63	19.35	21.76	HEMI	Salvo	8	6.1	
2nd Start										Waves	11	6.5	-1.67
End										Avon	13	191.2	-2.36
3rd Start													
End													
4th Start										Total			-3.05
End													
5th Start													
End													
6th Start													
End													



National Park Service Night Sky Team

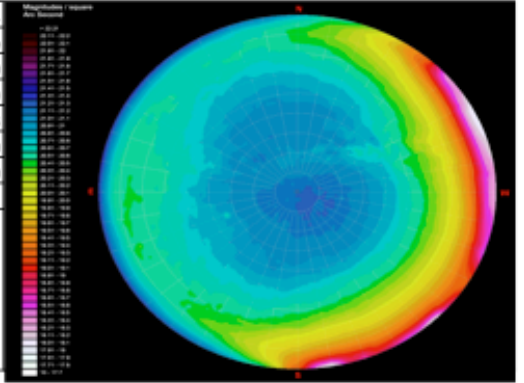


Night Sky Quality Monitoring Report

Report date: 2/26/08 by: C. Moore

PARK:	Cape Hatteras	EQUIPMENT:	IMG 3, 50mm f/2, Bessel V 6084
SITE NAME:	Bodie Island S of Maint Facility	OBSERVERS:	C. Moore
LONGITUDE:	-75.56135	AIR TEMP (°F):	60
LATITUDE:	35.84131	REL HUMID (%):	100
ELEVATION (m):	4	WIND SP (mph):	6
DATE (UT):	November 15, 2007	CCD TEMP (°C):	-20
TIME START (UT):	2:20:18	EXP (seconds):	10
DATA QUALITY:	Good	BORTLE CLASS:	"4-5" ZLM: ?

NARRATIVE: Only first of three data sets is good due to ice formation on cool camera window. Extinction was fairly high and nearby light sources were strongly scattered. Attempted another data capture (HT071115A) but ice problem persisted. This site is not ideal for discriminating light sources as many cities and facilities are in line with one another. Nearby light sources such as radio tower at 237, park housing at 310-330, and Oregon Inlet marina at 168 are visible, but cannot easily be separated. Subtle brightening to the east near may be backscatter from Kitty Hawk skyglow. With scattering so prevalent, had to estimate airglow index at 1.5. Milky Way is continuously visible from 20 degrees altitude across sky. Glare from lighthouse and skyglow interferes with night vision.

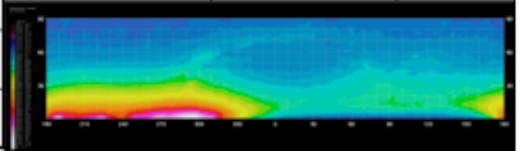


SKY BRIGHTNESS DATA

Data Set Number	Time (UT)	Extinction coefficient (mag/air-mass)	Std Err Y Extinction Stars (mags)	Zenith (mag/sq arc-sec)	Whole Sky (mags)	Sky Above 20° Altitude (mags)	Brightest (mag/sq arc-sec)	Darkest (mag/sq arc-sec)	Link to Sky Maps
1st Start	2:20:18			21.38					PAN
End	2:39:13	0.296	0.034	21.43	-8.13	-7.17	17.05	21.45	HEMI
2nd Start									
End									
3rd Start									
End									
4th Start									
End									
5th Start									
End									
6th Start									
End									

LIGHT DOME DATA

City	Distance (km)	Azimuth	1st Data Set Brightness (mags)
Manteo	11	304.0	
Nags Head, KDH, Kitty Hawk	13-29	333.0	-6.53
Wanchese	7	267.0	-5.32
Harbor	4	168.0	
Rodanthe, Salvo	29-34	165.0	-2.94
Lighthouse	2	184.0	-2.80
Total			-6.91



Night Sky Monitoring Data Page Explanation (From the NST website
<http://www.nature.nps.gov/air/lightscapes/monitorData/dataPageExplain.cfm>)

Observation Description

- **Park:** 4 letter park code.
- **Site Name:** Place name or local name of the monitoring site.
- **Longitude:** Longitude in decimal degrees (west is negative), Datum WGS 84, taken with GPS receiver, typical horizontal position accuracy 5 meters.
- **Latitude:** Latitude in decimal degrees (north is positive), Datum WGS 84, taken with GPS receiver, typical horizontal position accuracy 5 meters.
- **Elevation (m):** Elevation above mean sea level in meters, taken with GPS receiver, typical vertical positional accuracy 15 meters.
- **Date (UT):** The date at the beginning of data acquisition in Universal Time (GMT)
- **Time Start (UT):** The time in hours, minutes and seconds (24 hour clock) at the beginning of data acquisition in Universal Time (GMT).
- **Data Quality:** A semi-quantitative description of the quality or reliability of the data collected. Classes include: Excellent, Very Good, Good, Fair, and Poor. Data is classed according to many factors, including equipment malfunctions, battery voltage, unexpected image contamination by stray light, occurrence of frost or dew, observed layered haze or clouds, deviation of standard star measures from predicted values, and obvious visible defects in the images.
- **Equipment:** Short description of the camera, lens, and filter used. The filters used are all Bessell V astronomical filters transmitting green light.
- **Observers:** Name(s) of observers.
- **Air Temp (°F):** Air temperature at start of image acquisition as measured by a portable weather meter. Typical accuracy is 3 degrees.
- **Rel Humid (%):** Relative humidity at start of image acquisition as measured by a portable weather meter. Typical accuracy is 5%.
- **Wind Sp (mph):** Average wind speed at the start of image acquisition as measured by a portable weather meter held at eye level. Typical accuracy is 3 mph.
- **CCD Temp (°C):** Temperature at which the CCD camera's thermoelectric cooler is set at for data acquisition.
- **Exp (seconds):** Exposure (or integration) time of each image in seconds.
- **Bortle Class:** A qualitative measure of the sky quality observed visually, as developed by professional astronomer John Bortle. Classes are whole numbers 1-9, with 1 the very best and 9 the poorest.
- **ZLM:** Zenith limiting magnitude, or the faintest stars than can be observed visually without optical aid (naked eye) near the zenith or darkest part of the sky. There are 14,000 stars visible at 7.0 conditions, 5000 stars visible at magnitude 6.0 conditions, and only a few dozen stars visible at 1.0. This estimate varies somewhat from observer to observer. Faintest star visible is affected not only by artificial light pollution, but humidity, atmospheric clarity, and air turbulence also. Generally, pristine skies range from 6.6-7.5 while urban skies range from 0-4. More information can be found on the More information can be found on the Sonoma State University Observatory limiting magnitude webpage (http://www.phys-astro.sonoma.edu/observatory/observers/limiting_magnitude.html).
- **Narrative:** A descriptive narrative of the conditions observed visually during the night of data collection. Usually includes seeing (a measure of atmospheric steadiness), and transparency (a

measure of atmospheric clarity) in semi-quantitative terms. Also may include characteristics of the site and the visibility of certain astronomical features.

- **Image:** A compressed image of the all sky map of sky brightness in hemispheric projection. On this image, north is up and west is to the right- as if you were lying on your back looking at the sky with your head pointed north. Higher resolution images are available by clicking on HEMI in the Sky Brightness Data box.

Sky Brightness Data

- **Data set number:** Multiple data sets are usually taken on a given night. A data set is comprised of all the images necessary to cover the entire sky plus calibration images. Data sets are numbered sequentially.
- **Time (UT):** The time in hours minutes and seconds (24 hour clock) of the start and end of the data set in Universal Time (GMT).
- **Extinction coefficient (magnitude/airmass):** A measure of the opacity of the air, in astronomical magnitudes per airmass (atmospheric thickness). A star will be diminished in brightness or extinguished by this amount multiplied by the airmass through which it is observed. A star viewed at the exact zenith (straight overhead) is by definition viewed through 1 airmass. A star at 30 degrees above the horizon is viewed through 2 airmasses, and at 10 degrees above the horizon 5.6 airmasses. As an example, if the extinction coefficient is 0.20, a star with V magnitude of 4.0 will appear as magnitude 4.2 at the zenith, 4.4 when it is 30 degrees above the horizon, and 5.12 when it is 10 degrees above the horizon. The extinction coefficient is computed for each data set from measurements of 100-150 standard stars on the images through a range of airmasses. The extinction coefficient is corrected for a fixed color term for each instrument due to a slight bias in the V-band filter and camera combination.
- **Std Err Y Extinction stars (magnitudes):** Statistical standard error of Y of the extinction regression equation, expressed in astronomical magnitudes in V-band. Smaller numbers indicate a better fit to the linear model, which implies better data quality. A standard error of 0.04 magnitude is typical and considered to represent very good data quality.
- **Zenith (magnitudes/square arc-sec):** Sky brightness measured straight overhead. This and subsequent sky brightness measures are calculated from the median pixel value of a one degree diameter circle centered on the area of interest. This circle includes more than 1000 pixels. This value is converted to astronomical magnitude per square arc second (1/3600th of an angular degree or 1/12,960,000th of a square degree), a standard unit in the astronomical literature, in V-band. 22.0 is generally considered to represent pristine skies, lower values indicate a brighter sky due to variations in natural conditions or increased artificial light.
- **Whole Sky (magnitudes):** The brightness of the entire sky (excluding stars and glare from unshielded lights but including the Milky Way, Airglow, Zodiacal Light, and Light Pollution) in astronomical magnitudes in V-band. A value between -7.5 and -7.0 is typical for near pristine locations. Value more negative than -8.0 usually indicates degraded sky quality.
- **Sky Above 20 degree Altitude (magnitudes):** Like the previous measure but with the area between the horizon and 20 degrees altitude excluded. This would exclude small light domes from cities and most of the bright parts of the natural airglow. This is a more sensitive indicator of sky quality for dark locations. The presence of the Milky Way will significantly affect this value, however.
- **Brightest (magnitudes/square arc sec):** The brightness of the brightest part of the sky in magnitudes per square arc second in V-band. This is a median of a one degree circle, and excludes stars. It may be in a light dome from a city or in the Milky Way or other natural phenomena. The brightest value typically expected from a natural source (the Milky Way or

Zodiacal Light) is about 19.5. A value brighter (lower number) than this usually indicates degraded sky quality. A number lower than 17.0 represents a very bright area of the night sky and usually would significantly impair human night vision and cast obvious shadows on the land.

- **Darkest (magnitudes/square arc second):** The brightness of the darkest part of the sky above a point 20 degrees above the true horizon in astronomical magnitudes per square arc second in V-band. This is possibly the most directly comparable statistic between data sets and nights. However, it can vary significantly under natural (unpolluted) conditions from as bright as 21.3 to as dark as 22.3.

Light Dome Data

- **City:** The name of the cities, towns, or light sources producing the observed dome of light near the horizon.
- **Distance (km):** The distance of the light source from the monitoring site in kilometers.
- **Azimuth:** The azimuth or bearing in degrees (clockwise from true north) from the site to the light source.
- **Data set Brightness (magnitudes):** The total integrated brightness of the light dome in astronomical magnitudes in V-band calculated from the data indicated. Any number brighter (smaller) than -2.0 usually indicates a degradation in sky quality. For comparison, the planet Venus at its brightest is magnitude -4, a two day old crescent moon is magnitude -7.