Analysis of Great World Wide Star Count Data: 2007–2013

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Abstract The Great World Wide Star Count (GWWSC) website provides free public access to seven years of naked-eye limiting magnitudes (NELM) reported by citizen scientists from 2007 to 2013. We summarize the data and perform a simple statistical analysis. GWWSC data are compared with the Globe at Night (GaN) data over the same time period. The global average NELM values are generally comparable across the two data sets. Global NELM data seem to reflect shifts in urban versus suburban participation over time, while regional and local NELM data are more likely to reflect changes in night sky brightness.

1. Visual estimates of night sky brightness

The proliferation of man-made lighting for use at night produces a pervasive type of environmental problem known as light pollution (e.g. Dick 1999; Isobe and Hamamura 2000; Rich and Longcore 2005). Artificial light at night that scatters upward increases the brightness of the background sky (e.g. Garstang 1986, 1991; Cinzano and Falchi 2012). This increased brightness reduces the contrast between the background sky and faint stars: as the brightness of the sky increases, fainter stars become invisible to the naked eye (e.g. Moore 2001). This decrease in contrast can also render diffuse objects such as nebulae, galaxies, and the band of the Milky Way invisible.

Night sky brightness as seen from the ground can be estimated using the unaided human eye (e.g. Upgren 1991), photometers (Nawar *et al.* 1998), wide-field CCD cameras (Cinzano and Falchi 2003; Duriscoe *et al.* 2007), DSLR cameras (Zotti 2007), or commercially available Sky Quality Meters (e.g. Smith *et al.* 2008; Birriel *et al.* 2010). Naked-eye or visual estimates are semi-quantitative and subject to errors associated with observer age, visual acuity, and experience. However, visual estimates have several inherent advantages: they are essentially cost-free and can be done with relative ease and little time.

Thus, naked-eye estimates of night sky brightness are extremely useful for acquiring data over large geographic regions and long periods of time.

Night sky brightness can be estimated by examining a bright constellation for the faintest star observable with the naked eye, the so-called Naked-eye limiting visual magnitude (NELM). This is usually done using star charts (e.g. McBeath 1991). NELMs can be decreased by atmospheric turbulence, pollutants, and humidity. NELMs provide a "localized" measurement for the region of sky under examination; a full-scale picture of the sky could be obtained by multiple measurements of NELMs in different regions of the sky (e.g. Moore 2001). The NELM method is a seven-grade scale and requires only the ability to compare a set of charts to a given constellation in the sky. As a result of its ease of use and applicability to the full range of lighting conditions, NELMs are the method of choice for both the Globe at Night (GaN) and the Great World Wide Star Count projects.

2. The Great World Wide Star Count

The Great World Wide Star Count (GWWSC; http://starcount.org) is a citizen science event sponsored by the Windows to the Universe website (W2U; http://windows2universe.org) from the National Earth Science Teachers Association (http://nestanet.org). This W2U program began in 2007 at the University Corporation for Atmospheric Research (UCAR), where it resided until 2010.

The GWWSC observing campaign occurs each year during a two-week period, approximately mid-October to mid-November, when the lunar phase is between waning gibbous and first quarter. The campaign dates are further adjusted to include two full weekends to maximize observing opportunities for younger participants. The GWWSC protocol is similar to that of GaN—participants observe one of two constellations (Cygnus in the Northern Hemisphere and Sagittarius in the Southern Hemisphere), comparing their view with simple star maps of progressively fainter stars to determine the NELM value. The GWWSC was designed as a "complementary" program to GaN with compatible protocols and datasets. The principle differences between the two programs' NELM protocols are that GWWSC (1) takes place in October of each year and (2) utilizes two constellations located higher in the sky for northern and southern observers, while GaN originally took place during March and focused on Orion as being visible from both hemispheres.

Participation in the GWWSC is simple. The downloadable Activity Guide (available in fifteen languages) guides participants through the steps required for safe and successful participation. The actual measurement takes fifteen minutes, primarily waiting for the participant's eyes to dark-adapt. The reporting form closely resembles the online reporting page in order to provide a familiar user experience. Although measurements from commercial Sky Quality Meters are not directly supported, GWWSC participants are encouraged to enter SQM measurements in the comments field as desired. Once entered into the database via the online reporting form, each observation is instantly displayed on an interactive map, providing the participant with immediate confirmation that his or her observation was successfully submitted. After each annual campaign, the resultant datasets are published online in a variety of formats, including comma-separated values, tab-delimited text, and esri shapefiles (ESRI 1998). Global and regional light pollution maps are created by project staff and published online as well.

3. General summary and statistical analysis

It is of general interest to first note which countries are participating in the GWWSC. Sorting by country and counting the number of contributions from each country is easily done using built in functions in Microsoft EXCEL. The major contributions to GWWSC by country are listed in Table 1. The number of different countries with observations has generally decreased over the years, dropping from 66 countries in the inaugural year 2007 to only 31 countries in 2012 and 2013. It is immediately obvious that the United States, Poland, and Canada are generally major contributors to the GWWSC. Enhanced participation in Canada and Poland was primarily due to the interest and advocacy of their respective national astronomy clubs. In 2010 and 2011, India contributed a large number of data points from New Delhi; this is due to the public awareness campaign, the Great India Star Count (2014) which was conducted in partnership with the GWWSC.

Using the Histogram function in EXCEL, we can generate annual frequency histograms of the global NELMs from 2007 through 2013 (Figure 1). The general shape of the NELM histograms is roughly Gaussian with a peak NELM of about magnitude 4. As with GaN data (Birriel *et al.* 2014), the general shape and centroid of each histogram varies slightly from year to year. In any given year, approximately sixty percent of measured NELMs are between magnitudes 3 and 5.

Descriptive statistics are easily obtained using standard spreadsheet functions. In Table 2, we summarize the descriptive statistics of the GWWSC and GaN data for each year: counts (that is, the number of observations), mean, standard deviation, standard error, five sigma confidence level, and skewness. The means for GWWSC data are fairly comparable to the GaN means until the year 2012. The time evolution of aggregate NELMs from 2006 to 2013 is shown in Figures 2a and 2b. The correlation coefficient, $R^2 = 0.007$, is essentially zero.

The GWWSC data, Figure 2a, do not show the same general "brightening trend" from 2007 to 2012 as the GaN data as noted by Birriel *et al.* (2014). When we include the global mean for the 2013 GaN data, Figure 2b, the slope is still slightly negative and the correlation coefficient, $R^2 = 0.73$, indicates

Table 1. GWWSC contributions by country.

Year	*Number of Countries*	*Top Four Star Count Contributors by %*
2007	66	United States (83.0%), Canada (6.0%), United Kingdom (1.3%), Equatorial Guinea (1.3%)
2008	56	United States (76.3%), Poland (4.3%), Canada (3.5%), Brazil (1.7%)
2009	48	United States (73.5%), Colombia (5.3%), Poland (4.6%), France & United Kingdom (1.3% each)
2010	49	United States (59.4%), India (26.4%), Poland (6.6%), Canada & Chile (0.9%)
2011	52	United States (28.9%), India (46.4%), Poland (12.5%), Canada (7.0%)
2012	31	United States (40.8%), Canada (26.8%), Poland (20.5%), South Africa (2.2%)
2013	31	United States (36.3%), Poland (42.3%), Canada (13.6%), Argentina & Switzerland (1.7% each)

Table 2. Descriptive statistics. Great World Wide Star Count (GWWSC) compared to the Globe at Night (GaN).

Year	*Counts*		*Mean*		*Standard Deviation*		*Standard Error*		*5 Sigma Confidence*		*Skewness*	
	GWWSC	*GaN*	*GWWSC*	*GaN*	*GWWSC*	*GaN*	*GWWSC*	*GaN*	*GWWSC*	*GaN*	*GWWSC*	*GaN*
2007	5458	7261	3.91	3.80	1.50	1.38	0.02	0.02	0.04	0.07	–0.02	0.08
2008	2801	5295	4.07	3.82	1.47	1.34	0.03	0.02	0.05	0.08	–0.11	0.05
2009	1633	14063	3.84	3.69	1.39	1.26	0.03	0.01	0.07	0.05	–0.13	0.20
2010	4024	14394	3.77	3.73	1.53	1.42	0.02	0.01	0.05	0.05	–0.05	0.08
2011	5010	12461	3.24	3.38	1.52	1.27	0.02	0.01	0.04	0.05	0.21	0.12
2012	1921	14896	4.31	3.33	1.46	1.39	0.03	0.01	0.07	0.05	–0.22	0.21
2013	2194	15536	3.83	3.12	1.49	1.50	0.03	0.01	0.03	0.03	–0.02	0.33

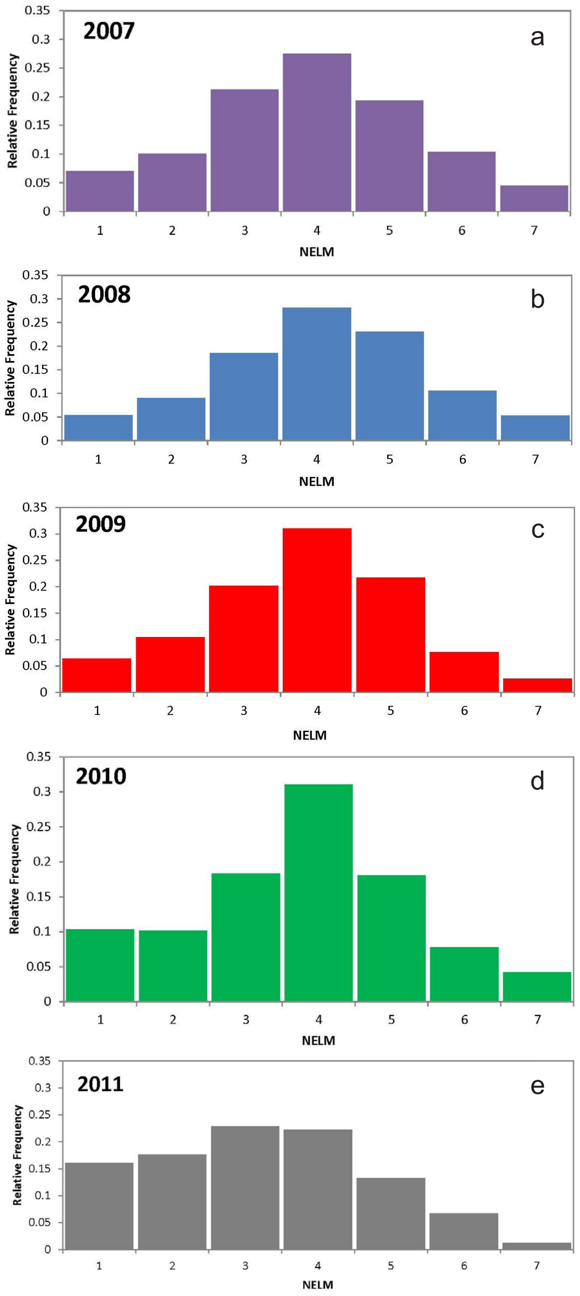

Figure 1a–e. Frequency histograms of naked eye limiting magnitudes (NELMs) for Great World Wide Star Count data from 2007–2013. Some variations occur from year to year but the distributions are roughly Gaussian with a peak around 4 (*Figure continued on next page*).

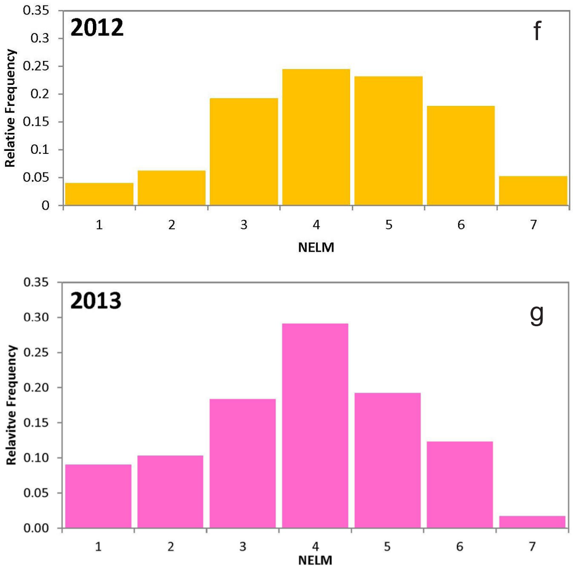

Figure 1f–g. Frequency histograms of naked eye limiting magnitudes (NELMs) for Great World Wide Star Count data from 2007–2013, cont.

Table 3. NELMs by groups for GWWSC data.

	NELM Grouping		
Year	*1+2*	*3+4*	*5+6+7*
2007	0.17	0.49	0.34
2008	0.14	0.47	0.39
2009	0.17	0.51	0.32
2010	0.21	0.49	0.30
2011	0.34	0.45	0.21
2012	0.10	0.44	0.46
2013	0.20	0.47	0.33

Note: NELMs 3+4 Corresponds to medium- to larger-sized cities.

that there is slightly less than a 5% chance that the aggregate NELMs are not correlated with time (Taylor 1997). We perform a one-tailed hypothesis test, with the null hypothesis that the slope is in fact zero for the GaN data. Using EXCEL to perform a linear regression analysis we find a p-value of 0.007, which makes the brightening trend significant at the 1% level. The GaN data appear to indicate a slight brightening of the global or aggregate NELM over the last eight years.

The aggregate NELM for each year of GWWSC data appears to fluctuate

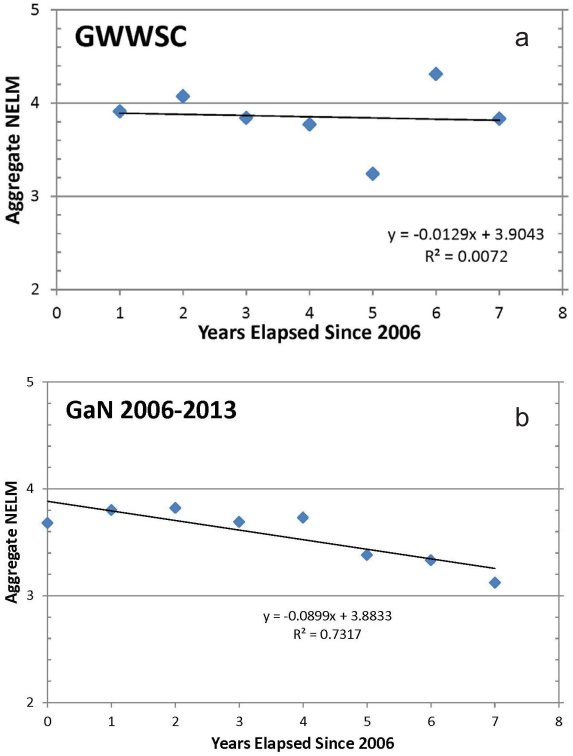

Figure 2a–b. Plots of the time evolution of aggregate or "global" NELM from 2006–2013 for (a) GWWSC and (b) GaN data. The zero year is 2006, which marks the first year of the GaN program. The GWWSC program began in 2007. While the GaN data appear to decrease slightly over time, the GWWSC data do not show this general trend. In both cases, the NELM appears relatively constant until 2010. The changes in NELM can be explained by the proportion of observers reporting from suburban-urban areas versus rural and pristine areas (Tables 2 and 3).

Table 4. NELMs by groups for GaN data.

	NELM Grouping		
Year	*1+2*	*3+4*	*5+6+7*
2007	0.14	0.58	0.28
2008	0.14	0.58	0.28
2009	0.13	0.65	0.22
2010	0.17	0.56	0.27
2011	0.21	0.61	0.18
2012	0.28	0.52	0.20
2013	0.31	0.48	0.21

Note: NELMs 3+4 Corresponds to medium- to larger-sized cities substantially from 2010 to 2013. On the other hand, from 2007 to 2010 the global mean appears to be relatively constant. A NELM of magnitude 3–4 corresponds to an observing location of a medium- to larger-sized city, while a NELM of magnitude 5–7 corresponds to smaller cities and rural areas. A NELM of magnitude 1–2 means that the observer was located in a highly light-polluted inner city region. In Table 3 we present the annual frequency of each of these three categories for the GWWSC data. From 2007 to 2010, the aggregate contribution in each category remains relatively constant. Note, however, from 2010 to 2013, the aggregate NELM first drops by about 0.5 magnitude from 2010 to 2011, then increases by about 1 magnitude from 2011 to 2012, and then decreases again by about 0.5 magnitude from 2012 to 2013. An examination of Table 3 indicates that these changes reflect changes in the fraction of observers reporting from rural/suburban areas versus large and inner city regions. For example, between 2010 and 2011 the fraction of observers reporting NELMs from magnitudes 1 to 2 increases by thirteen percent while the fraction of observers reporting NELMs from magnitudes 5 to 7 decreases by nine percent. From 2011 to 2012 the aggregate NELM increases by just over 1 magnitude and Table 3 indicates that the fraction of observers reporting from very light-polluted areas drops by 24% and the fraction of observers reporting from less light-polluted areas increases by 25%. In the case of GWWSC data, changes in the aggregate NELM over the 2007–2013 period do not simply reflect changes in light levels, they also show the strong influence of the fraction of observers reporting from rural/suburban versus large/inner city locations.

The same trend appears in the GaN data, at least to some extent. An examination of Table 2 and Figure 2b show that the aggregate NELM of GaN data are all relatively close and the data all exhibit a very small, but similar, skew. The mean NELM has remained relatively constant over the duration of the GaN project: for the first five years the mean remained essentially constant at about magnitude 3.74, but in the last three years the average dropped slightly to magnitude 3.36. Between 2010 and 2011, the aggregate NELM in the GaN data decreases by 0.35 magnitude and the decrease continues for subsequent years. In Table 4, we see that there has been a shift in the fraction of observers reporting from heavily light-polluted areas versus more less light-polluted areas. Between 2010 and 2011, the fraction of observers reporting from suburban and rural areas decreased by 9% while there was a corresponding increase of 4% of observers reporting from the most light-polluted areas. Each subsequent year shows a relatively constant fraction of reporters from suburban/rural areas; however, the fraction of reports from medium-sized cities decreases while the fraction of reports from large/inner city regions increases.

One particularly interesting difference between the GWWSC and GaN data sets is the skewness of the data (see Table 1). In every year but 2011, the skewness of GWWSC data is slightly negative while the GaN data always have a slightly positive skewness. Why might this be the case? The GWWSC constellations for determining NELM are Cygnus and Sagittarius, which were chosen partially to minimize airmass and light dome effects from nearby cities and towns. However, both of these constellations lie in the band of the Milky Way. The GaN constellation used for NELM determination through 2010 was Orion. Since 2011, the GaN has evolved to include more campaigns and use more constellations. We posit that the GWWSC observers tend to over-estimate night sky brightness compared to GaN observers due to the reduced contrast of stars in Cygnus and Sagittarius relative to the brighter than average natural background from the diffuse light of the Milky Way. The year 2011 might be skewed to the positive due to prevailing weather patterns that year; we suggest that GWWSC and GaN data could be used to study the impact of weather on NELMs.

4. Discussion and future directions

The aggregate annual NELMs for GWWSC and GaN data are generally in good agreement, with a difference of less than 0.2 magnitude, until 2012. This agreement is fairly remarkable given the differences in sample size. However, this can be explained by the fact that from 2007 through 2010, both programs had participants that were dominated by U.S. contributions (see Tables 1 and 5). From 2011 to 2013, U.S. contributions to each campaign were less then 50%. Over the last two years, the three largest contributors to the GWWSC campaigns have been the U.S., Canada, and Poland, whereas the top contributors to the GaN campaigns have been the U.S., India, Poland, and South Korea (almost exclusively from the heavily populated cities of Seoul and Busan). These last two years show the largest difference in aggregate mean. We conclude that this difference is the result of the regional differences in light practices in Asia versus Eastern Europe and Canada.

So, beyond educating the public about light pollution, what is the value of the GWWSC data? GWWSC data is collected in a manner identical to GaN data, using citizen scientists who obtained naked-eye limiting magnitudes by comparing their sky to seven charts of a constellation. Kyba *et al.* (2013) have demonstrated that aggregate GaN data are an accurate tracer of artificial light at night. Kyba *et al.* point out that the great value of GaN data is that aggregate values can ultimately be used to measure increases in sky-glow as measured from the ground up, particularly as the time span increases. In addition, GaN data should be useful for tracking regional changes. We suggest that the GWWSC can be used in conjunction with GaN data to track the rate of change of sky glow both regionally and globally.

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Table 5: GaN contributions by country.

Year	*Number of Countries*	*Top 4 Contributors by %*
2007	62	United States (65.9%), Poland (5.0%), Hungary (3.1%), Canada (3.1%),
2008	61	United States (76.3%), Hungary (5.6%), Romania (2.8%), Czech Republic (2.8%)
2009	81	United States (73.6%), Chile (6.1%), Hungary (1.7%), United Kingdom (1.4%)
2010	85	United States (61.4%), Poland (4.7%), Romania (3.7%), Chile (3.5%)
2011	113	United States (48.0%), Poland (8.5%), India (5.0%), South Korea (3.2%)
2012	92	United States (36.0%), India (14.7%), Poland (7.1%), Argentina (5.2%)
2013	89	United States (39.2%), India (12.4%), South Korea (5.8%), Poland (5.4%)

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