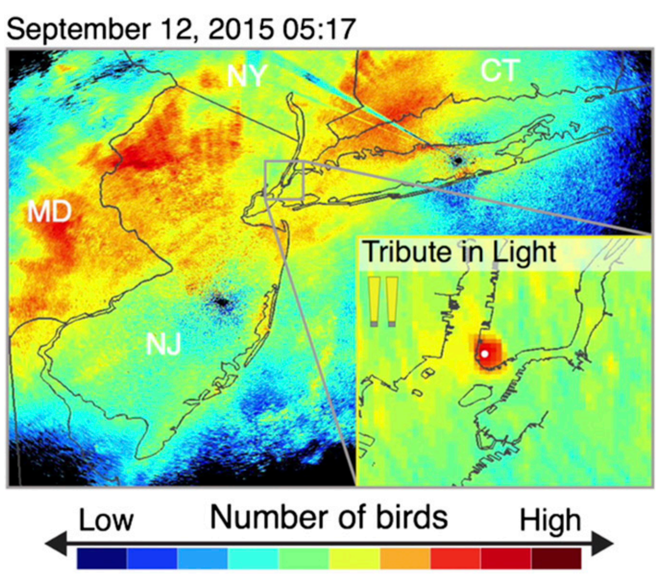
Supporting Information

Van Doren et al. 10.1073/pnas.1708574114

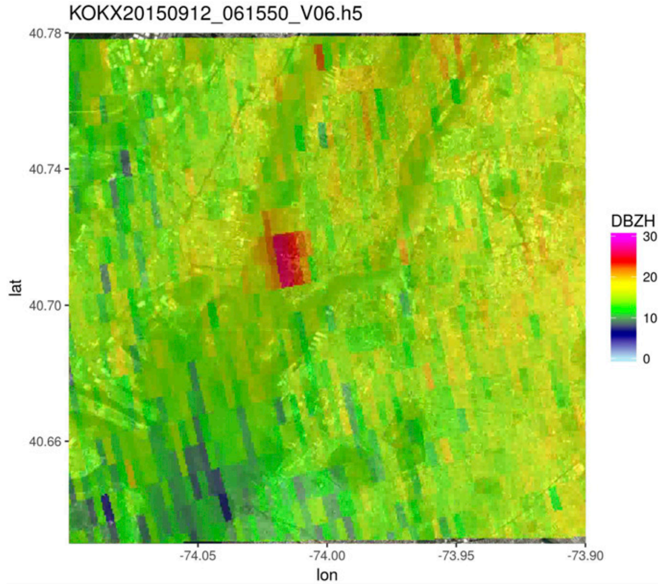
Movie S1. Birds in active migration above Tribute in Light in 2015. Media depicting the spectacle of nocturnally migrating birds at the site are also archived electronically, among other locations, on YouTube (https://www.youtube.com/playlist?list=PLcUZ2YcGkUo55aftE9kzEJ04kwBiNYlYW) and on Flickr (https://www.flickr.com/photos/67181840@N07/with/29572530441/).

Movie S1



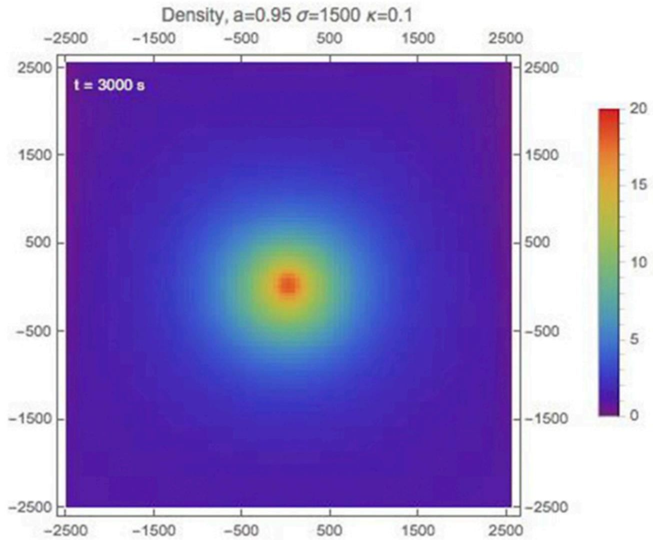
Movie S2. Animation of radar data for the coverage area of NYC radars and the installation site (*Inset*) for the 2015 TiL. It shows heavy bird migration (redder colors) concentrated over the installation during periods of illumination (TiL light symbol in *Upper Left* of *Inset* filled with yellow) and decreased density during periods of darkness (TiL light symbol filled with gray).

Movie S2



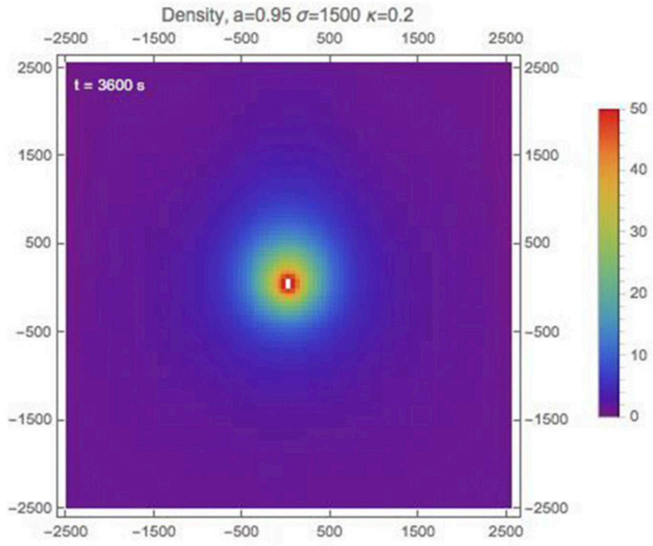
Movie S3. Animation of 0.5° elevation reflectivity scans of KOKX radar (dBZ) overlaid on satellite image of New York City. The bird accumulations above Tribute in Light appear as bright pink pixels above lower Manhattan.

Movie S3



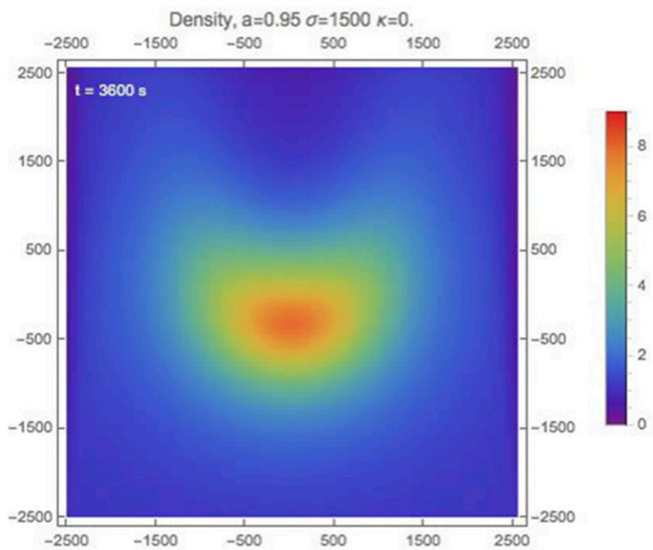
Movie S4. Simulation results of spatial bird densities for model 1 (Fig. 4 and *SI Appendix*, Table S1). Lights are switched off at 3,600 s (60 min). Note the different density scale for each simulation video.

Movie S4



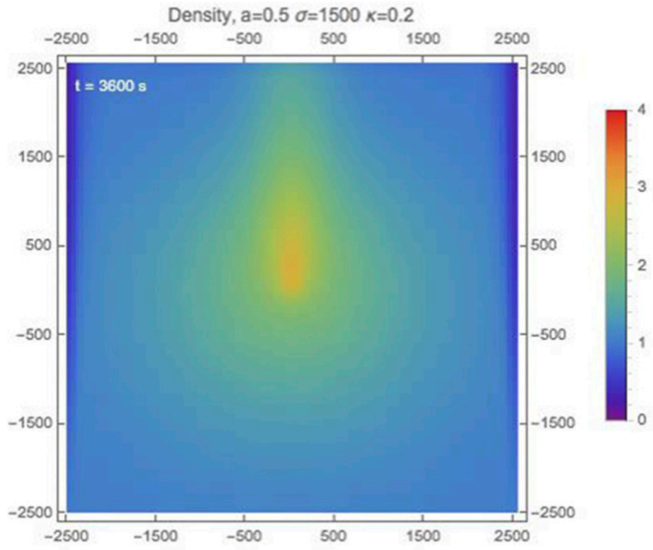
Movie S5. Simulation results of spatial bird densities for model 2 (Fig. 4 and *SI Appendix*, Table S1). Lights are switched off at 3,600 s (60 min). Note the different density scale for each simulation video.

Movie S5



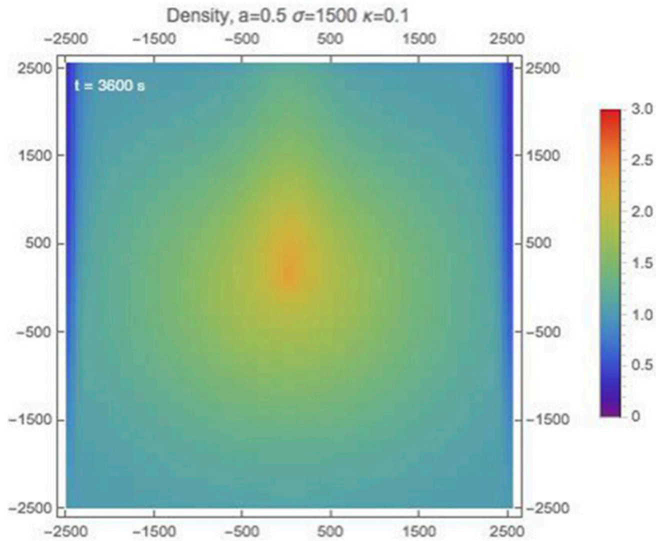
Movie S6. Simulation results of spatial bird densities for model 3 (Fig. 4 and *SI Appendix*, Table S1). Lights are switched off at 3,600 s (60 min). Note the different density scale for each simulation video.

Movie S6



Movie S7. Simulation results of spatial bird densities for model 4 (Fig. 4 and *SI Appendix*, Table S1). Lights are switched off at 3,600 s (60 min). Note the different density scale for each simulation video.

Movie S7



Movie S8. Simulation results of spatial bird densities for model 5 (Fig. 4 and *SI Appendix*, Table S1). Note the different density scale for each simulation video.

Movie S8

Other Supporting Information Files

SI Appendix (PDF)
Dataset S1 (XLSX)

Supporting Information

High-intensity urban light installation dramatically alters nocturnal bird migration

Benjamin M. Van Doren, Kyle G. Horton, Adriaan M. Dokter, Holger Klinck, Susan B. Elbin, and Andrew Farnsworth

SI Methods

Study Site. Tribute in Light consists of two ground-based installations of lights, each comprising 44 7,000-8,000-watt xenon bulbs pointing skyward, giving the appearance of two tall towers of light. The bulbs have a dichroic treatment as well as nickel rhodium reflectors that significantly reduce infrared and ultraviolet spectra and create an effect similar to daylight. Beam projection and visibility is highly dependent on weather conditions, but the columns of light can project vertically from thousands of meters to tens of kilometers and are visible from distances up to 100 km.

At the time that the agreement for shutting down the installation in the presence of birds was developed, there was no information available about the dynamics of how birds arrive and depart the tribute site, nor was there information about how the installation affected behaviors. The shutdown process takes several minutes to complete because each bulb of the two 44-bulb installations must be turned off individually. Once dark, lights remained off for 22 ± 6 SD minutes. A dark period of approximately 20 minutes represented the best consensus among all stakeholders to balance potentially conflicting interests to maintain the integrity and intent of the event and to remove the attractive stimulus to birds, allowing them to depart from the area of potential hazard.

Weather Data. Weather data included details of temperature, visibility, wind direction and speed, and general conditions (Table S3) as well as more detailed cloud ceiling and cover aloft (Table S4). Clear skies prevailed among the 77 hourly LCD observations, with 66 of 77 hours (85.7%) exhibiting conditions described as clear or mostly clear skies. Local visibility never dropped below 11 km on any of our monitoring nights, and visibility of 16 km or greater occurred in 66 of 77 samples (87.5%). Visibility was at maximum (18.5 km) for 71 of 77 hours, with the remaining six hours never dropping below 13.0 km. Additionally, cloud cover was less than 50% for all but eight hours, generally 12.5% or less, and never below 0.5 km above the ground, mostly 0.5-1.5 km above the ground (Table S4). Thus, we did not classify any of these nights as poor visibility conditions.

Weather Surveillance Radar. In addition to the methods presented in the main text, a number of methodologies were important for our calculations of metrics describing the influence of the installation. To quantify the total number of birds affected by the installation, we estimated the number of birds within 5 km of the installation up to a height of 4.5 km using data from the 0.5° elevation angle and applying the correction factors described in the main text (Fig. S10). We did this for all radar scans across all years. The correction factors allowed us to estimate the total number of birds present from altitudes of 0-4.5 km given the number of birds detected in the 0.5° sweep. For comparison, we calculated the average bird density between 10-20 km from the installation and found the expected number of birds within 5 km of the installation, assuming densities were the same as those 10-20 km away. The difference between the expected number and the directly measured number was our estimate of the number of birds influenced by the installation in that radar scan. When the density of birds near the installation was lower than baseline, we set the number of birds affected to zero for that scan. Because our simulations (see below) provide information on the actual turnover time, we arrived at a total estimate that avoids double-counting birds by subsampling our dataset by a factor equal to the median time between radar scans (9.5 minutes) divided by the stabilization time estimate. For example, if the average turnover time is 20 minutes and the median time between radar scans is 10 minutes, we would subsample by a factor of 10/20 = 0.5, summing on average every other radar scan. To quantify uncertainty in our estimate, we calculated 95% confidence intervals by subsampling 10,000 times and finding the 0.025 and 0.975 quantiles of the resulting values.

We also analyzed data from the radar sweep with an elevation angle of ≈1.5°. This sweep intersects the airspace above the installation at an altitude of approximately 3.2 km (50% power range 2.4-4.1 km), twice as high as the 0.5° sweep. These altitudes are at the upper limit of bird migration, particularly passerines, in this region (e.g. 1, 2). Using the approach described in the main text, we calculated the number of birds in a cylinder of radius 0.5 km along the ground and height 1.7 km. We did not apply an additional multiplier.

To construct standardized visuals (e.g. Fig. 1*B,C*; Movies S2, S3) of the area of influence during periods of illumination, we cast radar resolution cells of the 0.5° elevation sweep to a regular spatial grid (i.e. raster image, ≈0.002° x 0.002°) using an equidistant cylindrical projection. We used maximum values of reflectivity and those nearest the radar for radial velocity when two or more resolution cells occupied a cell. We used the mean value in each cell for periods with and without illumination for aggregate plotting.

Acoustic Analysis. Because of the high intensity of calling activity at the site, in which many calls overlapped in time and frequency, and to minimize effects of different microphones, we used the amplitude in the 6-9 kHz frequency band to derive an index of calling activity. We applied a 10^{th}-order Butterworth band-pass filter with corner frequencies 6 kHz and 9 kHz to the dataset (see Fig. S6). We then calculated mean amplitude values for the 6-9 kHz frequency band for consecutive one-minute non-overlapping windows. Finally, we normalized the resulting time series to obtain a relative calling activity index, hereafter "normalized amplitude." A normalized amplitude of 1 represents the maximum observed calling activity.

To estimate numbers of calls from normalized amplitude, we manually counted flight calls from spectrograms (Hann Window, FFT size 512, overlap 87.5%, 375 Hz grid spacing; (3)) in 40 one-minute periods during the night of 11 September 2015. We randomly selected these periods during the night, while ensuring that there was equal representation from each quartile of the normalized amplitude distribution. Normalized amplitude was an excellent predictor of vocal activity ($R^2 = 0.90$, $P < 0.0001$; Fig. S11), demonstrating that it is an appropriate measure of vocal activity from flight calls. In this linear model, we forced the regression through the origin to avoid the impossible scenario of negative flight calls (i.e. there should be zero normalized amplitude when there are zero calls, but this assumes no interfering noises, which was not always the case).

In order to directly compare acoustic and radar observations with linear models, we downsampled acoustic observations to the frequency with which radar observations were gathered. We achieved this by simply selecting the nearest one-minute calling sample for each radar observation, provided that it occurred within three minutes of the radar observation.

Visual Observations. Visual observations represented, to the best of observers' abilities, estimates of numbers, species, and flight behaviors of birds. AF used Zeiss and Kowa optics (10 x 50 binoculars and 20-60 zoom x 85 spotting scope, respectively, in 2008, 2010, and 2012-2015) and Swarovski optics (12 x 50 binoculars and 30-70 x 95 spotting scope in 2016). These observations are archived as specified in the Methods. See Movie S1.

Hypothetically, decreases in average radial velocities observed by radar for nocturnally migrating birds during periods of illumination could mean either that birds' mean flight speeds slowed as they passed the installation, or that individual birds maintained flight speeds but, because many birds started circling, appeared to decrease in average speed relative to the radar station. We used visual observations to determine which of these scenarios was occurring.

Statistical Analyses. We used generalized additive models (R package mgcv (4)) to quantify the effects of illumination on birds' behaviors. We tested the categorical factors of light (on/off) and year on four metrics: standardized peak density; the total number of birds present within 0.5 km of the installation; the radial velocities of birds above the installation; and the number of flight calls recorded beneath the site. We looked separately at 0.5° and 1.5° radar sweeps. Because the light shutdown procedures took several minutes to complete, and to allow birds time to respond to the change of treatment, we excluded data points within 5 minutes of an on/off transition. In addition to the categorical factors listed above, we included two smooth terms (thin plate regression splines with basis dimension chosen automatically): 1) time of night and 2) mean bird density between 2-20 km away, fitted separately for each year. These terms accounted for any overall variation in densities and behavior through each night unrelated to local light pollution (e.g. due to weather factors and regular circadian patterns; see (5-7)) and additionally served to account for autocorrelation. Importantly, in our model of vocal activity, we also included the peak bird density above the installation (as measured by radar) as a continuous predictor to account for variation in calling explained simply by the number of birds present. For each metric, we compared models with three possible combinations of categorical factors: light alone; light and year; and light and year with an interaction. We evaluated these models with the Akaike Information Criterion (AIC) and selected the model with the lowest AIC score. However, if the model with the lowest AIC score was within 1 AIC unit of a model with fewer parameters, we used the more parsimonious model. We checked the distribution of model residuals and applied data transformations when necessary. Initially, the residuals for the models of standardized peak density, total number of birds, and number of flights calls were highly skewed, and it was necessary to apply a log transformation to these response variables. We used the *logst* transformation in the R package *regr0* (8), which is equivalent to a $\log_{10}$ transformation for all but the smallest values, which are scaled such that the transformation yields all finite values. We chose this option because, unlike adding an arbitrary constant value to all observations, this method of scaling small values is determined by the distribution of the data. It only modifies the smallest observations, leaving all others unchanged. For models with log-transformed response variables, we express effect size as a multiplicative factor, found by exponentiating the coefficient.

In addition to testing for average differences in bird numbers between light and dark periods over the entire night, we looked at changes in peak concentrations between periods. We compared measurements made during periods of darkness (up to 30 minutes in duration) to those made during adjacent 30-minute illuminated periods. In each period, we found the maximum values of standardized peak density and total number of birds for both 0.5° and 1.5° sweeps. We constructed linear models as above, but without smooth terms because autocorrelation was not an issue. Again, we tested for the best of three possible models using AIC. We log-transformed response variables to satisfy model assumptions.

Figures were produced using the R packages *lattice* (9), *Hmisc* (10), *ggplot2* (11), and *cowplot* (12).

Simulations. We defined our simulations with the following assumptions. A bird in the migratory state could fly undisturbed in an average preferred migratory direction. Birds enter the disoriented state following a normal probability distribution f (see Fig. S8*A*) that decreases with distance (d) from the light.

$$f(d \mid a, \sigma) = a e^{-\frac{d^2}{2\sigma^2}} \tag{1}$$

Here, a is the model parameter specifying the maximum probability to disorient when a bird is within (or very near) the lights. The standard deviation (σ) specifies the characteristic distance from the light at which birds become disoriented. In the disoriented state, birds depart from their preferred migratory direction and draw their flight direction from circular normal distribution g (von Mises distribution, see Fig. S8*B*):

$$g(\alpha|\alpha_{\text{light}}, \kappa) = \frac{e^{\kappa \cos(\alpha - \alpha_{\text{light}})}}{2\pi I_0(\kappa)} \tag{2}$$

with α_{light} the angular direction of the lights at the position of the bird, I_0 the modified Bessel function of order 0, and κ the concentration parameter. When $\kappa = 0$ the function g is uniform, and birds' flight paths follow a random walk. When $\kappa > 0$ there is a preferential flight direction towards the lights, with larger κ implying a more directed flight towards the light source.

The simulation model thus has three main parameters

- a, the probability of disorientation
- κ, the concentration parameter for disoriented flight, determining the extent to which birds fly towards ALAN when disoriented
- σ, the characteristic distance from the lights within which ALAN affects bird behaviors

The simulation grid had a 5 x 5 km extent, with grid cells of 50 x 50 m. The simulation time step Δt = 10 s. In each simulation step, we determined the proportion of birds in that cell affected by ALAN using Equation (1). We propagated these disoriented birds over a distance $\Delta t\ v_{bird}$ into directions given by the angular distribution of Equation (2). We propagated the remaining birds in the migratory state over an equal distance into the preferred migratory direction.

Model parameters were fit to the radar observations in years 2010, 2012, 2013, 2015 and 2016, when lights were manipulated. Simulations were performed on the basis of lights-on periods, in which we assumed the baseline migration density and speed to be constant. The baseline migration ground speed v_{bird} was calculated at the location of KOKX, using a vertical profile extraction following the methods of (13). The baseline migration density was calculated as the average bird density in the area 2-20 km distance from the installation, assuming a cross-section per bird of 8.1 cm^2. The peak density at the installation for each radar scan was calculated as the maximum density observed within 500 m of the installation. The frame of reference is rotated such that the birds' migratory directions were upward towards the lights, located in the center of the simulation grid. We excluded the first lights-on period after sunset, as bird densities change rapidly in this time window, and to not be affected by potentially different behavior during takeoff or when it is not fully dark. This gave 20 lights-on periods in total for the 5 years.

The model was fit by an exhaustive search in the model parameter space, considering a=0.25-0.98 (steps of 0.1), κ=0-0.8 (steps of 0.1), and σ=250-2000 m (steps of 250 m). All possible combinations of parameter values were tested in separate model runs coded in Wolfram Mathematica 11, requiring ≈12 days of CPU time on a

2.3 GHz Intel Core i5 processor. Goodness-of-fit of the simulation was quantified by the explained variance in peak density at the ALAN source, defined as $1-S_{err}/S_{tot}$, with S_{err} the sum of squared residuals between simulated and measured peak density, and S_{tot} the sum of squares of measured peak density. Explained variance for all parameterizations is reported in Table S2.

We visualized simulation runs for a high (a =0.95) and a low (a =0.5) disorientation probability, as well as for moderately strong (κ=0.2) and weak (κ=0.1) attraction to light (see Fig. 4). Parameterizations are illustrated in Fig. S8. We extracted from the runs the bird density increase factor at the ALAN source and a stabilization time, defined as the time required to reach 95% of the steady state peak density at the ALAN source.

1. La Sorte FA*, et al*. (2015) Seasonal changes in the altitudinal distribution of nocturnally migrating birds during autumn migration. *Royal Society Open Science* 2(12):150347.
2. Bellrose FC (1971) The distribution of nocturnal migrants in the air space. *The Auk* 88(2):397-424.
3. Bioacoustics Research Program (2011) *Raven Pro: interactive sound analysis software. Version 1.4* (The Cornell Lab of Ornithology, Ithaca, New York, USA).
4. Wood SN (2011) Fast stable restricted maximum likelihood and marginal likelihood estimation of semiparametric generalized linear models. *Journal of the Royal Statistical Society: Series B (Statistical Methodology)* 73(1):3-36.
5. Farnsworth A*, et al*. (2016) A characterization of autumn nocturnal migration detected by weather surveillance radars in the northeastern USA. *Ecol. Appl*. 26(3):752-770.
6. Van Doren BM, Horton KG, Stepanian PM, Mizrahi DS, & Farnsworth A (2016) Wind drift explains the reoriented morning flights of songbirds. *Behavioral Ecology* 27(4):1122-1131.
7. Van Doren BM, Sheldon D, Geevarghese J, Hochachka WM, & Farnsworth A (2015) Autumn morning flights of migrant songbirds in the northeastern United States are linked to nocturnal migration and winds aloft. *The Auk* 132(1):105-118.
8. Stahel W (2017) regr0: Building regression models. R Package version 1.0-5/r80.
9. Sarkar D (2008) *Lattice: Multivariate Data Visualization with R* (Springer, New York).
10. Harrell Jr. FE (2017) Hmisc: Harrell Miscellaneous. R package version 4.0-3.
11. Wickham H (2009) *ggplot2: Elegant Graphics for Data Analysis* (Springer-Verlag, New York).
12. Wilke CO (2017) cowplot: Streamlined Plot Theme and Plot Annotations for 'ggplot2'. R package version 0.8.0.
13. Horton KG, Van Doren BM, Stepanian PM, Farnsworth A, & Kelly JF (2016) Seasonal differences in landbird migration strategies. *The Auk* 133(4):761-769.

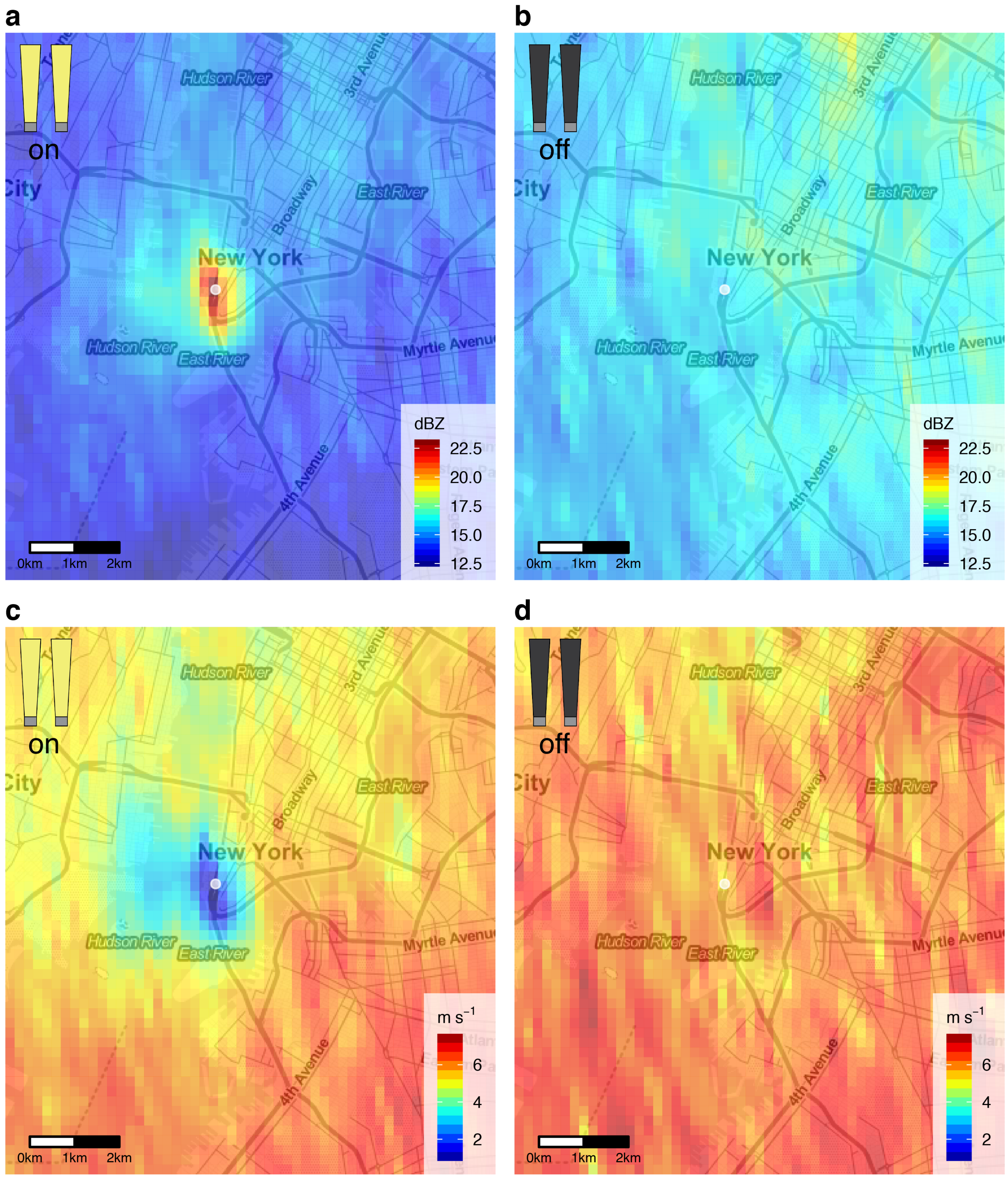


Fig. S1. Area of ALAN influence on nocturnally migrating birds at Tribute in Light, 11-12 September 2015. Bird density close to the installation (white dot) with illumination **a** was noticeably higher than in the surrounding area and without illumination **b**; radial velocity with illumination **c** was noticeably lower than in the surrounding area and without illumination **d**. Each cell shows the mean value for illuminated **(a, c)** and dark periods **(b, d).**

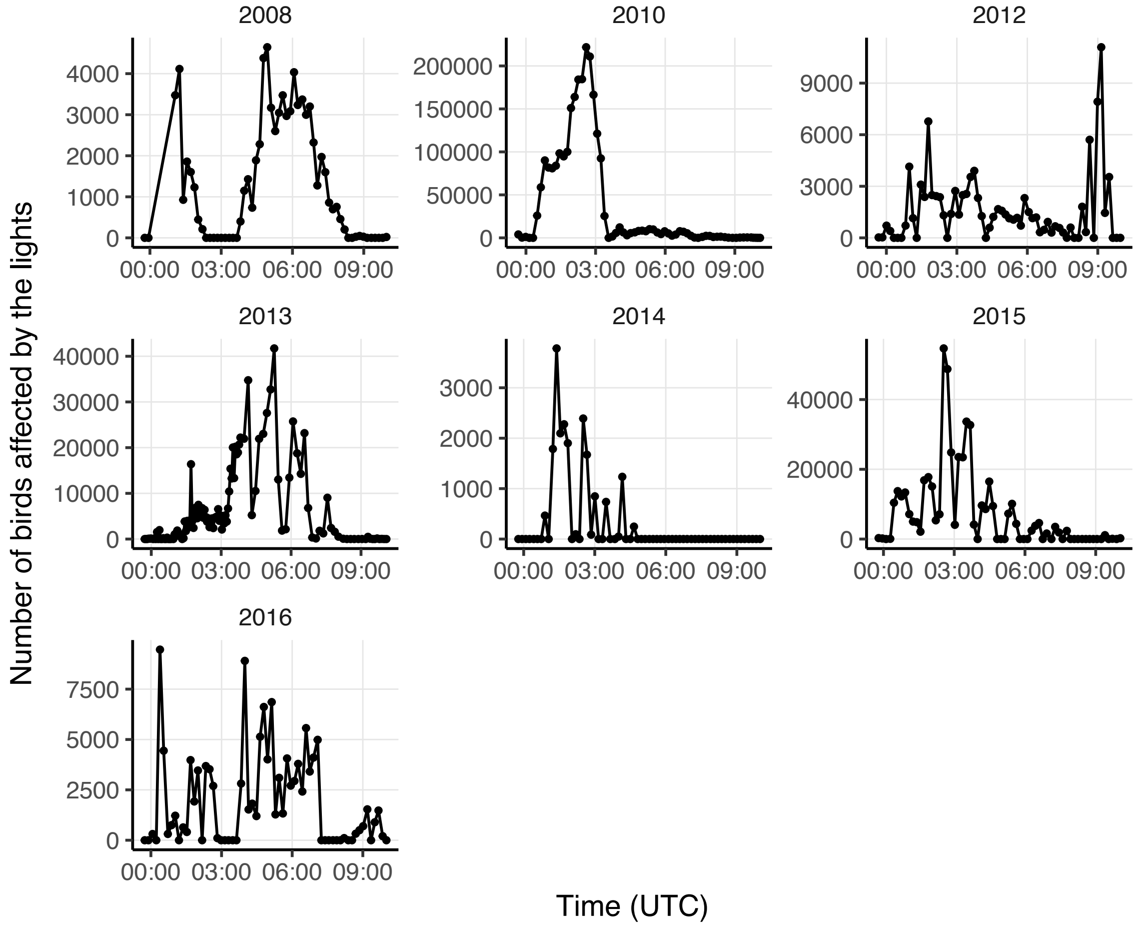


Fig. S2. Numbers of birds affected by Tribute in Light by year. Presented are differences between bird numbers within 5 km of the installation and the number expected in that area given baseline densities from 10-20 km away (Fig. S3). To arrive at an estimate of a total of 1.1 million birds (95% CI: 0.6-1.6 million) affected during the study, we divided the median time between radar scans of 9.5 minutes by the simulated stabilization time of 34 minutes (Fig. 4) and summed this proportion (≈0.28) of the dataset.

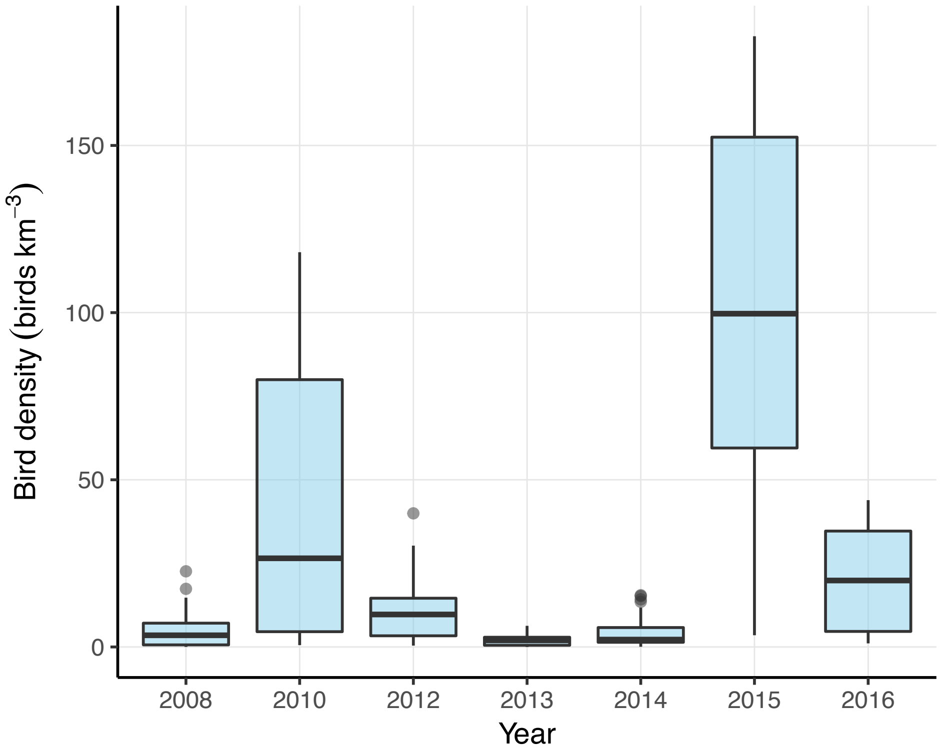


Fig. S3. Baseline bird density around Tribute in Light by year. Bird densities between 10-20 km from the installation as detected by the 0.5º elevation angle radar beam.

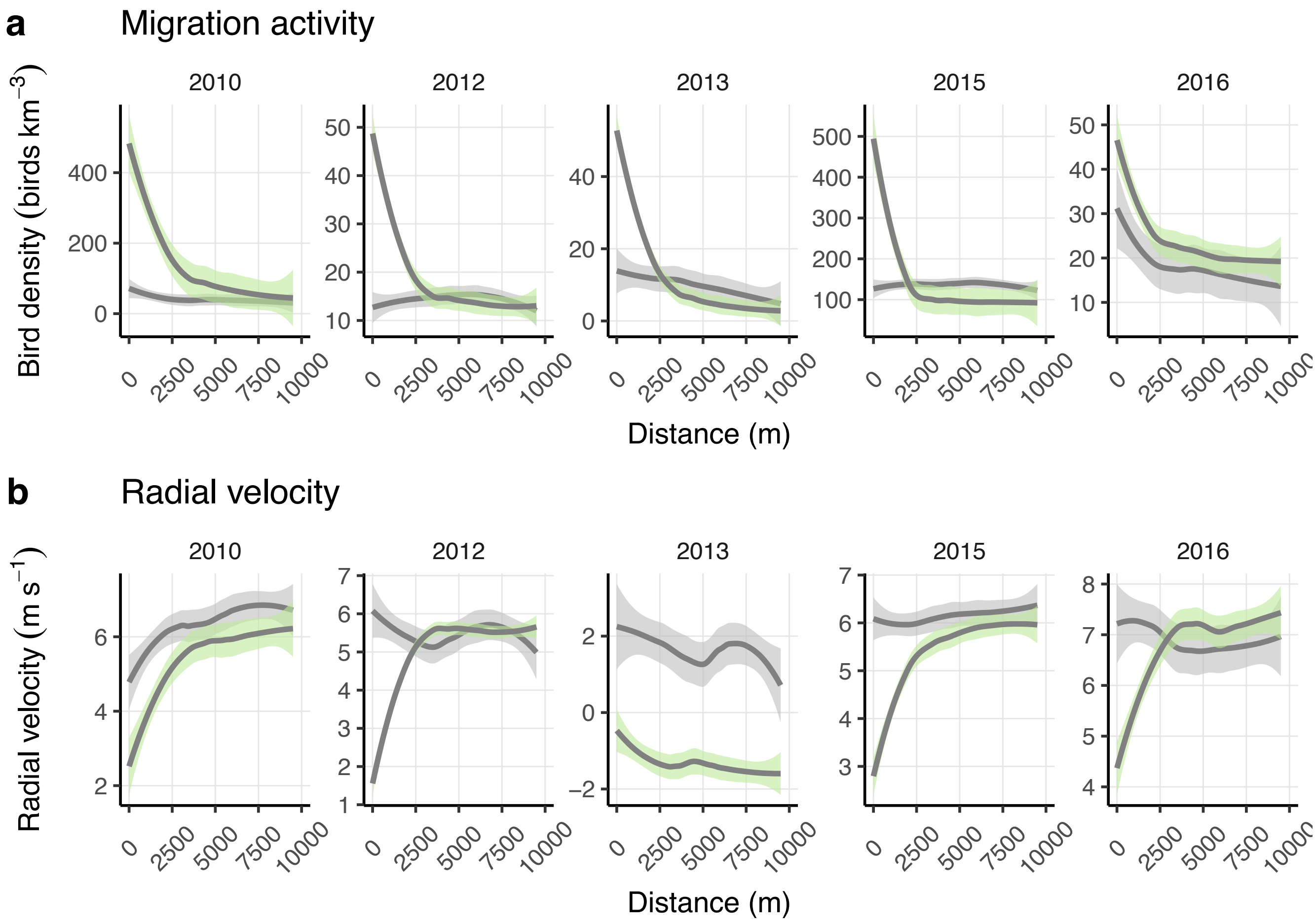


Fig. S4. Bird migration behavior by distance from Tribute in Light by year. Radar-measured bird density and radial velocity with increasing distance from the installation, with (green shading) and without (gray shading) illumination. Curves are local polynomial regression surfaces (*loess* function). Included are the five years during which light shutdowns occurred.

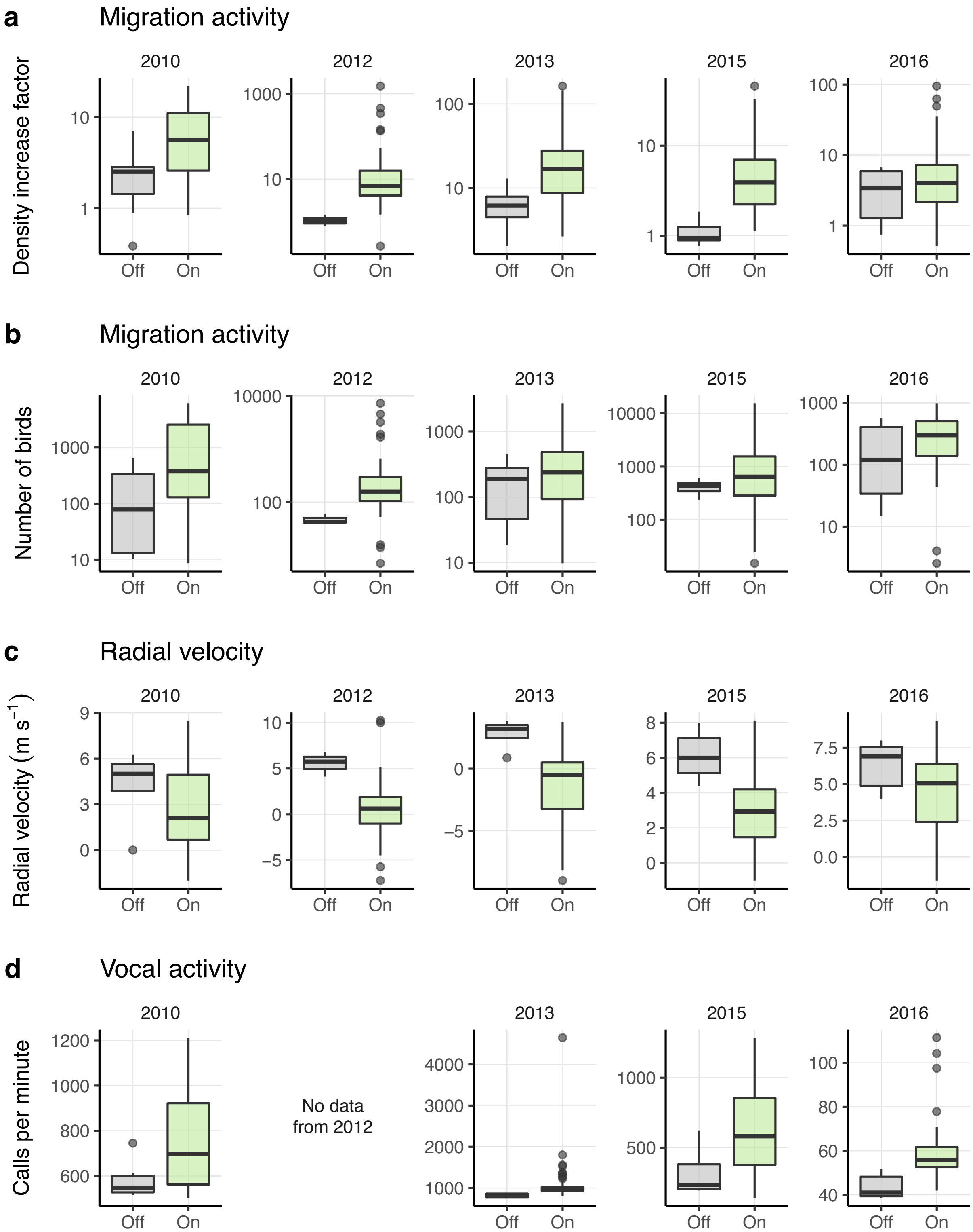


Fig. S5. Boxplots showing four behavioral metrics with and without illumination by year. (a) Density increase factor, defined as peak bird density within 500 m of the installation divided by mean bird density between 2-20 km from the site. Data points calculated from very low bird densities (baseline less than 0.1 birds km^{-3}) are not shown. (b) Estimated number of birds in the cylinder with radius 500 m and height 4.5 km, directly above the site. (c) Radial velocity 0-500 m from the site. (d) Number of flight calls per minute detected beneath the installation. Included are the five years during which light shutdowns occurred.

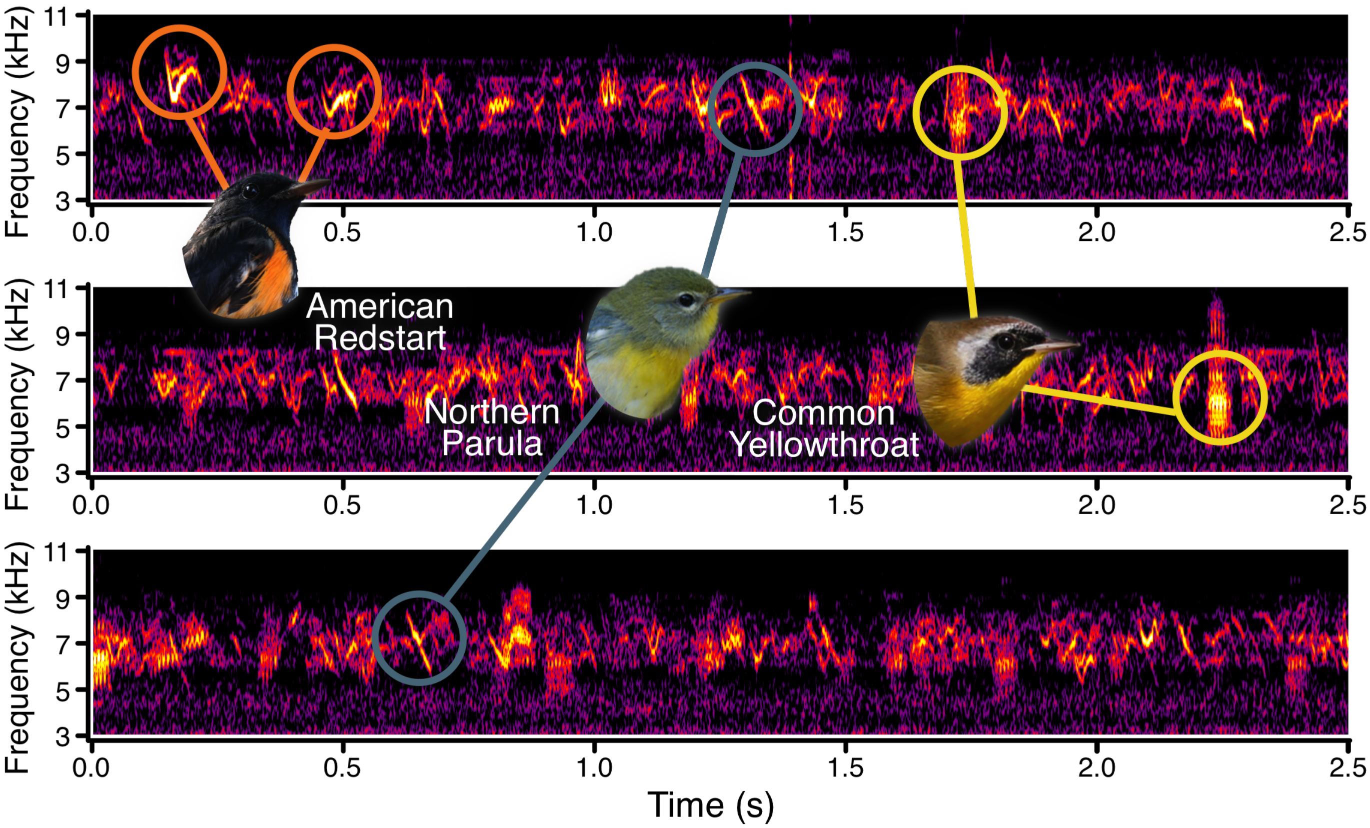


Fig. S6. Vocal activity of nocturnally migrating birds above Tribute in Light. Spectrographic representation of vocal activity in a 7.5-second audio sample from 12 September 2015, 0549 UTC (Coordinated Universal Time). Areas of brighter colors, such as reds, oranges, and yellows, have higher amplitude (i.e. are louder) than areas of purple or black. Note the large numbers of flight calls in the 6-9 kHz frequency range of this recording from an illuminated period at the installation, including many calls that overlap in frequency and time; we applied a band-pass filter to quantify acoustic energy within this frequency range. Among the diversity of species represented in this sample, circles highlight the calls of three species of American wood-warblers (family Parulidae) that were numerous at the study site: American Redstart, *Setophaga ruticilla* (orange), Northern Parula, *Setophaga americana* (blue), and Common Yellowthroat, *Geothlypis trichas* (yellow). Photos: American Redstart, Kyle Horton; Northern Parula, Ian Davies/Macaulay Library, eBird S24916843; Common Yellowthroat, William Keim/Macaulay Library, eBird S31689615.

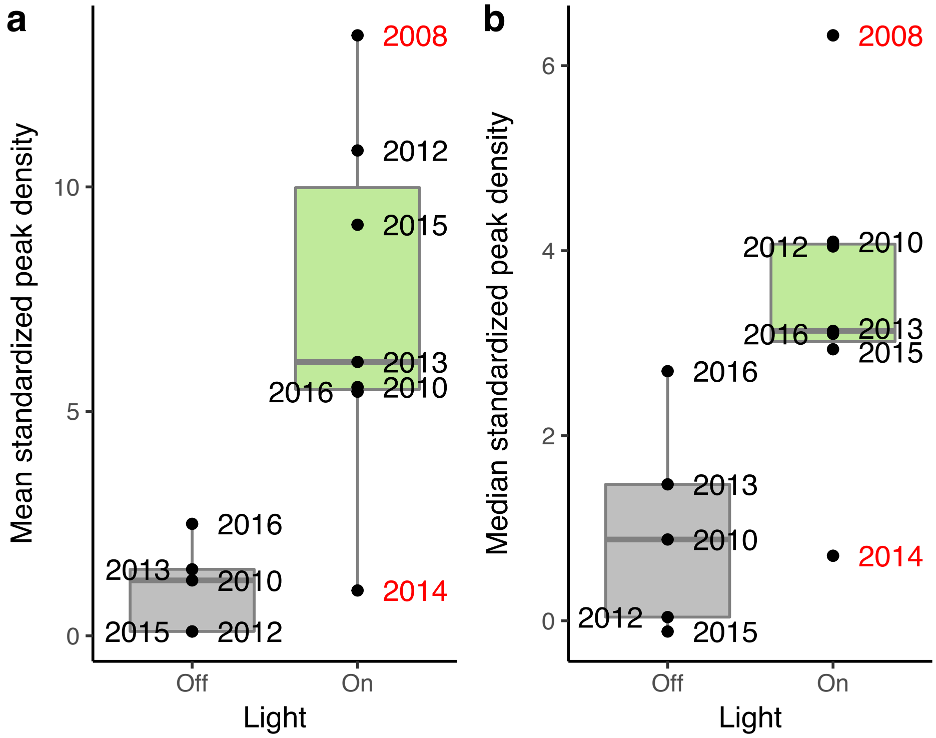


Fig. S7. (a) Mean and (b) median values of standardized peak density at Tribute in Light for 2008-2016 by illumination, excluding 2009 and 2011 due to the presence of precipitation. Lights were not turned off in 2008 or 2014 (shown in red), and therefore these years were excluded from core analyses. Note that 2008 showed an above-average concentration effect, while 2014 showed a below-average concentration effect. In other words, the five years included in the core analyses fell comfortably between the two years that were not included because no shutdowns occurred. Therefore, based on the available data, we conclude that the five primary study years are representative of typical light effects at the installation.

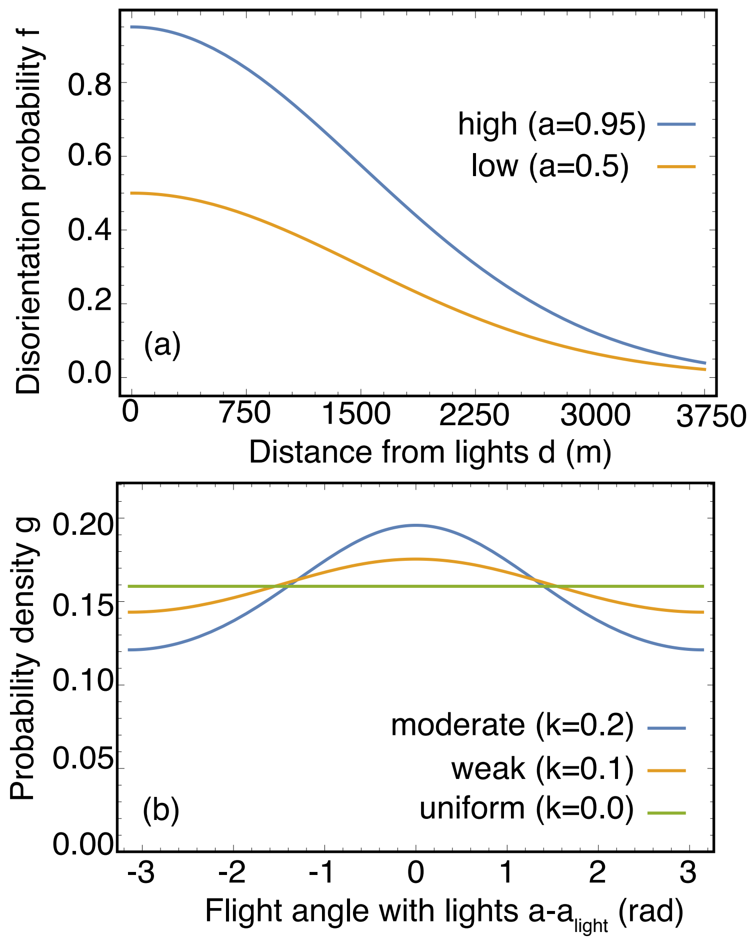


Fig. S8. Model simulation of disorientation. In the simulation, birds could transition between an undisturbed migratory state and a disoriented state. (a) Parameterizations of the distance-dependent disorientation probability f (Equation 1). a is the probability of disorientation. (b) Parameterizations of the angular Von Mises distribution g (Equation 2) for the case of uniform ($\kappa = 0$), moderate ($\kappa = 0.2$) and weak ($\kappa = 0.1$) directed flight towards ALAN for birds in the disoriented state. κ is the concentration parameter for disoriented flight, determining the extent to which birds fly towards ALAN when disoriented. When $\kappa = 0$, birds' flight paths follow a random walk; when $\kappa > 0$, birds fly toward the lights, with larger κ implying a more directed flight towards the light source.

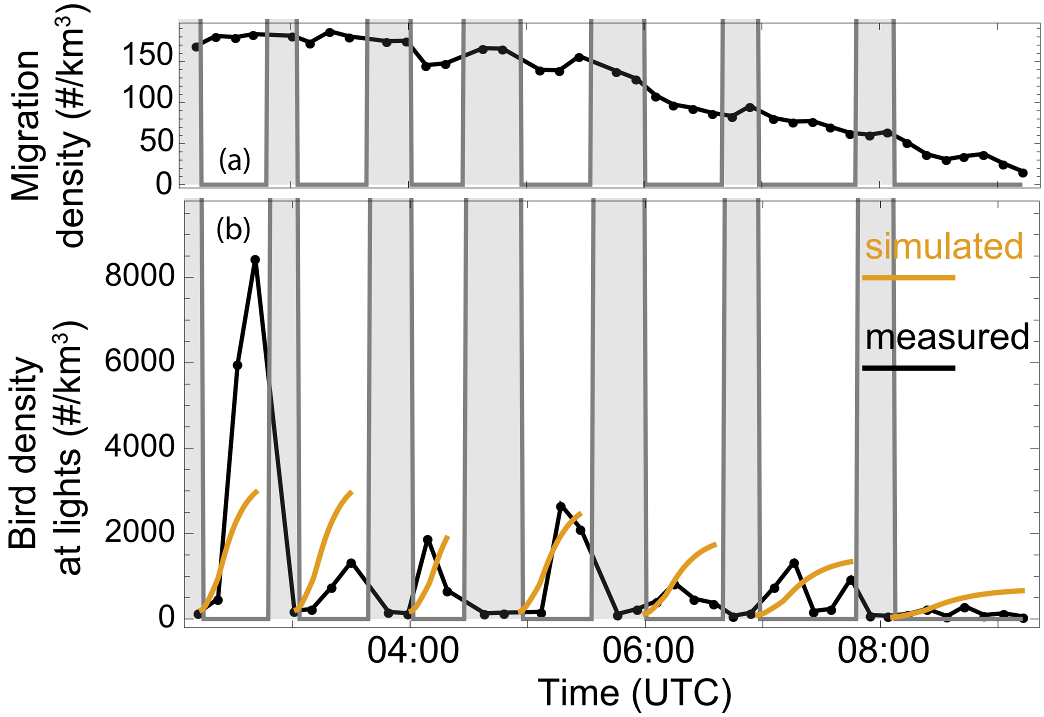


Fig. S9. Simulated and measured regional and local migration on 11-12 September 2015. (a) Background migration density (birds km^{-3}) in regions not affected by ALAN. This density is the mean migration density between 2-20 km from Tribute in Light. (b) Bird density at the installation as recorded with the KOKX radar in 2015. Shaded areas indicate periods when lights were off. This density is peak density observed within 500 m of the installation. Simulated densities during light-on periods are given in orange, using the parameterization of the best model fit (model 1).

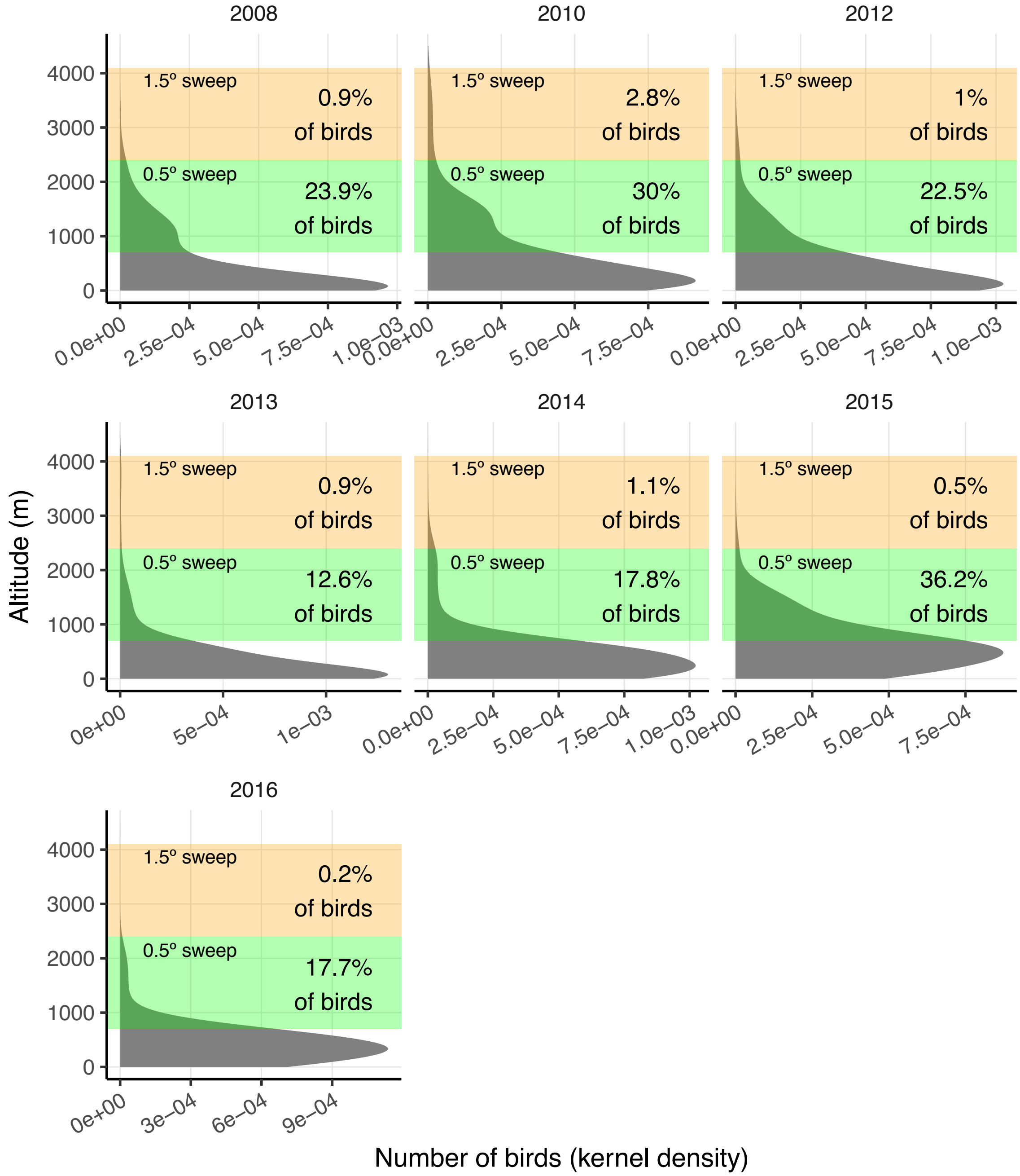


Fig. S10. Proportion of nocturnal bird migration by altitude and radar sweep coverage by year at Tribute in Light. Vertical profiles of bird density constructed from radar data between 5-60 km from the KOKX radar in New York. Each panel represents a different year. We calculated the proportion of migration occurring beneath (or above) the radar beam at the light installation, out of sight of the radar. Labels describe the percentage of birds detected in the altitude (y-axis) sampled by each radar antenna elevation angle (0.5º in green, 1.5º in orange). From the 0.5º sweep proportions, we calculated the correction factor needed to estimate the total number of birds at all altitudes up to 4.5 km by finding the inverse. For example, the correction factor for 2015 was 1/0.362 = 2.76.

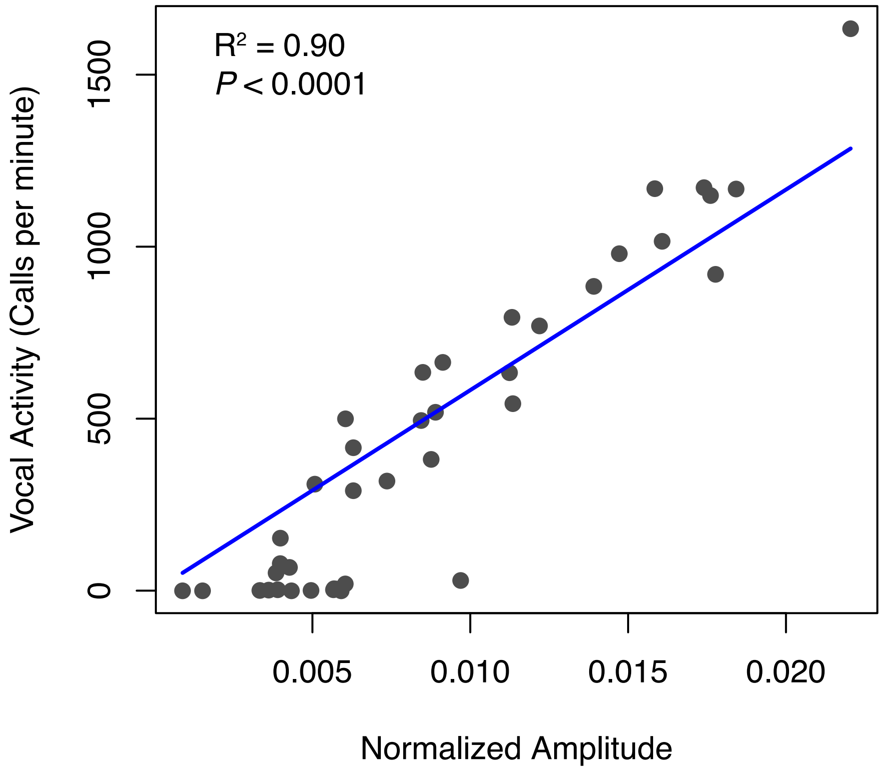


Fig. S11. Relationship of flight call count and normalized amplitude, a calling activity index. Regression of vocal activity on normalized amplitude for flight calls of nocturnally migrating birds in the 6-9 kHz range for 11-12 September 2015. Vocal activity is the number of flight calls counted in each one-minute audio recording. Normalized amplitude is the mean amplitude for the 6-9 kHz frequency band in each one-minute audio recording, normalized to unit.

Table S1. Representative parameterizations of the simulation model, including the best fit parameters.

	Disorientation probability	Disoriented flight directionality	Disorientation distance (σ)	Stabilization time [min]	Density increase factor
Model 1 (best fit)	High (a=0.95)	Weak (κ=0.1)	1500	34	19
Model 2	High (a=0.95)	Moderate (κ=0.2)	1500	51	42
Model 3	High (a=0.95)	None (κ=0)	1500	24	8.0
Model 4	Low (a=0.5)	Moderate (κ=0.2)	1500	6.5	3.0
Model 5	Low (a=0.5)	Weak (κ=0.1)	1500	6.7	2.3

Stabilization time is defined as the time required to reach 95% of the steady state peak density at the lights, for a migratory ground speed of 10 m/s. Density increase factor is a multiplicative factor relative to the baseline migration density ρ.

Table S2. Ranking of parameterizations of the migratory flow model (see Equation 2 for parameter definitions).

Rank	a	σ	κ	Explained variance
1	0.95	1500	0.1	0.513
2	0.95	1750	0.1	0.511
3	0.98	1250	0.1	0.510
4	0.95	1250	0.1	0.506
5	0.95	2000	0.1	0.506
6	0.98	1500	0.1	0.505
7	0.98	1000	0.1	0.502
8	0.98	1750	0.1	0.497
9	0.98	2000	0.1	0.489
10	0.95	1000	0.1	0.484
11	0.85	1250	0.2	0.480
12	0.85	1500	0.2	0.478
13	0.85	1750	0.2	0.473
14	0.85	1000	0.2	0.470
15	0.75	2000	0.3	0.469
16	0.85	2000	0.2	0.467
17	0.75	1750	0.3	0.466
18	0.75	1500	0.3	0.463
19	0.98	750	0.1	0.461
20	0.75	1250	0.3	0.457
21	0.98	500	0.2	0.449
22	0.65	2000	0.4	0.448
23	0.75	1000	0.3	0.443
24	0.65	1750	0.4	0.443
25	0.95	750	0.2	0.439
26	0.65	1500	0.4	0.436
27	0.95	750	0.1	0.435
28	0.75	750	0.4	0.434
29	0.65	1000	0.5	0.434
30	0.85	750	0.2	0.433
31	0.95	500	0.2	0.432
32	0.75	2000	0.2	0.431
33	0.55	1500	0.7	0.431
34	0.65	1250	0.5	0.430
35	0.55	1250	0.7	0.430
36	0.75	500	0.5	0.430
37	0.55	1750	0.7	0.429
38	0.85	2000	0.1	0.429
39	0.55	2000	0.6	0.429
40	0.95	250	0.6	0.429
41	0.85	1750	0.1	0.427
42	0.65	750	0.6	0.427
43	0.55	2000	0.7	0.427
44	0.85	250	0.8	0.426
45	0.55	1750	0.6	0.425

46	0.55	1000	0.8	0.425
47	0.65	1250	0.4	0.425
48	0.65	500	0.7	0.425
49	0.75	1750	0.2	0.425
50	0.85	500	0.4	0.424
51	0.98	250	0.5	0.424
52	0.55	1000	0.7	0.423
53	0.55	750	0.8	0.423
54	0.85	500	0.3	0.421
55	0.65	1500	0.5	0.421
56	0.98	250	0.6	0.421
57	0.85	1500	0.1	0.420
58	0.55	1500	0.6	0.420
59	0.85	750	0.3	0.419
60	0.65	500	0.8	0.419
61	0.65	750	0.5	0.418
62	0.85	250	0.7	0.417
63	0.75	1500	0.2	0.415
64	0.98	1250	0	0.413
65	0.95	500	0.3	0.413
66	0.98	1500	0	0.412
67	0.95	250	0.5	0.412
68	0.65	1750	0.5	0.412
69	0.55	1250	0.6	0.411
70	0.75	750	0.3	0.410
71	0.55	1250	0.8	0.409
72	0.65	1000	0.4	0.407
73	0.85	1250	0.1	0.404
74	0.65	2000	0.5	0.404
75	0.98	1750	0	0.403
76	0.65	500	0.6	0.401
77	0.55	750	0.7	0.401
78	0.75	500	0.4	0.400
79	0.98	1000	0	0.399
80	0.75	1250	0.2	0.399
81	0.75	500	0.6	0.395
82	0.55	1000	0.6	0.395
83	0.95	250	0.7	0.394
84	0.45	2000	0.8	0.392
85	0.55	2000	0.5	0.391
86	0.75	1000	0.4	0.391
87	0.75	250	0.8	0.389
88	0.65	2000	0.3	0.389
89	0.85	250	0.6	0.388
90	0.55	1500	0.8	0.388
91	0.98	2000	0	0.388
92	0.45	1750	0.8	0.387
93	0.98	250	0.4	0.387
94	0.55	1750	0.5	0.386
95	0.65	1750	0.3	0.384
96	0.65	1000	0.6	0.381
97	0.55	1500	0.5	0.379
98	0.45	1500	0.8	0.379
99	0.95	1500	0	0.378
100	0.95	1250	0	0.378
101	0.65	1500	0.3	0.377
102	0.55	500	0.8	0.377
103	0.85	1000	0.1	0.377
104	0.98	500	0.1	0.375
105	0.75	1000	0.2	0.374
106	0.65	750	0.4	0.374
107	0.95	1750	0	0.370
108	0.98	750	0.2	0.369
109	0.55	1250	0.5	0.369
110	0.95	250	0.4	0.369
111	0.45	1250	0.8	0.368
112	0.55	1750	0.8	0.368
113	0.98	750	0	0.366
114	0.95	1000	0	0.366
115	0.55	750	0.6	0.366
116	0.65	1250	0.3	0.365
117	0.65	750	0.7	0.365
118	0.65	500	0.5	0.361
119	0.45	2000	0.7	0.358
120	0.75	250	0.7	0.358
121	0.95	2000	0	0.358
122	0.85	500	0.2	0.355
123	0.45	1750	0.7	0.353
124	0.95	500	0.1	0.353
125	0.55	1000	0.5	0.352
126	0.45	1000	0.8	0.352
127	0.98	500	0.3	0.350
128	0.85	250	0.5	0.350
129	0.55	2000	0.8	0.350

130	0.65	1000	0.3	0.347
131	0.45	1500	0.7	0.346
132	0.55	500	0.7	0.345
133	0.75	500	0.3	0.343
134	0.98	250	0.3	0.340
135	0.95	750	0	0.338
136	0.75	750	0.2	0.338
137	0.98	250	0.7	0.337
138	0.85	750	0.1	0.337
139	0.55	2000	0.4	0.336
140	0.45	1250	0.7	0.335
141	0.55	1750	0.4	0.332
142	0.55	1500	0.4	0.327
143	0.45	750	0.8	0.326
144	0.55	750	0.5	0.324
145	0.75	250	0.6	0.322
146	0.95	250	0.3	0.322
147	0.45	1000	0.7	0.320
148	0.45	2000	0.6	0.320
149	0.65	250	0.8	0.319
150	0.75	750	0.5	0.319
151	0.55	1250	0.4	0.318
152	0.45	1750	0.6	0.315
153	0.65	750	0.3	0.315
154	0.65	500	0.4	0.314
155	0.98	500	0	0.312
156	0.55	500	0.6	0.311
157	0.45	1500	0.6	0.309
158	0.85	250	0.4	0.307
159	0.75	1250	0.4	0.305
160	0.65	1250	0.6	0.304
161	0.55	1000	0.4	0.304
162	0.75	1750	0.1	0.304
163	0.75	2000	0.1	0.303
164	0.65	2000	0.2	0.303
165	0.65	1750	0.2	0.302
166	0.75	1500	0.1	0.301
167	0.45	1250	0.6	0.300
168	0.65	1500	0.2	0.298
169	0.45	750	0.7	0.297
170	0.75	1250	0.1	0.295
171	0.65	1250	0.2	0.292
172	0.95	500	0	0.291
173	0.98	250	0.2	0.291
174	0.65	250	0.7	0.291
175	0.45	1000	0.6	0.287
176	0.75	250	0.5	0.285
177	0.75	1000	0.1	0.282
178	0.85	500	0.1	0.282
179	0.45	500	0.8	0.281
180	0.55	750	0.4	0.280
181	0.75	500	0.2	0.279
182	0.45	2000	0.5	0.279
183	0.65	1000	0.2	0.279
184	0.85	1250	0	0.278
185	0.95	250	0.2	0.276
186	0.85	1500	0	0.276
187	0.55	2000	0.3	0.276
188	0.45	1750	0.5	0.276
189	0.55	500	0.5	0.275
190	0.55	1750	0.3	0.274
191	0.85	1000	0	0.273
192	0.35	2000	0.8	0.272
193	0.55	1500	0.3	0.271
194	0.45	1500	0.5	0.271
195	0.95	250	0.8	0.271
196	0.85	1750	0	0.271
197	0.35	1750	0.8	0.269
198	0.65	500	0.3	0.267
199	0.45	750	0.6	0.267
200	0.55	1250	0.3	0.266
201	0.85	250	0.3	0.265
202	0.45	1250	0.5	0.264
203	0.35	1500	0.8	0.264
204	0.85	2000	0	0.263
205	0.65	250	0.6	0.262
206	0.85	750	0	0.259
207	0.75	750	0.1	0.259
208	0.45	500	0.7	0.257
209	0.35	1250	0.8	0.256
210	0.65	750	0.2	0.256
211	0.55	1000	0.3	0.256
212	0.55	250	0.8	0.254
213	0.45	1000	0.5	0.253

214	0.75	250	0.4	0.252
215	0.85	1000	0.3	0.250
216	0.98	250	0.1	0.248
217	0.35	2000	0.7	0.247
218	0.35	1000	0.8	0.245
219	0.35	1750	0.7	0.244
220	0.95	1000	0.2	0.242
221	0.55	500	0.4	0.240
222	0.35	1500	0.7	0.240
223	0.45	2000	0.4	0.239
224	0.85	500	0.5	0.238
225	0.55	750	0.3	0.238
226	0.45	1750	0.4	0.237
227	0.45	750	0.5	0.237
228	0.95	250	0.1	0.236
229	0.45	1500	0.4	0.234
230	0.75	500	0.7	0.234
231	0.65	250	0.5	0.234
232	0.35	1250	0.7	0.234
233	0.85	500	0	0.233
234	0.55	250	0.7	0.233
235	0.45	500	0.6	0.232
236	0.85	250	0.2	0.232
237	0.45	1250	0.4	0.229
238	0.35	750	0.8	0.229
239	0.75	500	0.1	0.225
240	0.65	1500	0.6	0.224
241	0.35	1000	0.7	0.224
242	0.65	1500	0.1	0.224
243	0.65	1750	0.1	0.223
244	0.35	2000	0.6	0.222
245	0.65	1250	0.1	0.222
246	0.65	500	0.2	0.222
247	0.98	250	0	0.221
248	0.45	1000	0.4	0.221
249	0.65	2000	0.1	0.221
250	0.75	250	0.3	0.221
251	0.55	1750	0.2	0.220
252	0.55	2000	0.2	0.220
253	0.35	1750	0.6	0.220
254	0.55	1500	0.2	0.220
255	0.55	1250	0.2	0.217

256	0.35	1500	0.6	0.216
257	0.65	1000	0.1	0.216
258	0.55	250	0.6	0.212
259	0.35	1250	0.6	0.212
260	0.95	250	0	0.211
261	0.75	1250	0	0.211
262	0.55	1000	0.2	0.211
263	0.75	1500	0.4	0.211
264	0.75	1000	0	0.210
265	0.35	750	0.7	0.210
266	0.45	500	0.5	0.209
267	0.75	1500	0	0.208
268	0.45	750	0.4	0.208
269	0.55	500	0.3	0.208
270	0.65	250	0.4	0.207
271	0.35	500	0.8	0.204
272	0.75	750	0	0.204
273	0.35	1000	0.6	0.204
274	0.65	750	0.1	0.204
275	0.75	1750	0	0.204
276	0.45	2000	0.3	0.202
277	0.85	250	0.1	0.202
278	0.45	1750	0.3	0.201
279	0.45	250	0.8	0.200
280	0.45	1500	0.3	0.200
281	0.55	750	0.2	0.198
282	0.75	2000	0	0.198
283	0.35	2000	0.5	0.198
284	0.45	1250	0.3	0.196
285	0.35	1750	0.5	0.196
286	0.75	250	0.2	0.194
287	0.35	1500	0.5	0.194
288	0.35	750	0.6	0.192
289	0.55	250	0.5	0.192
290	0.45	1000	0.3	0.191
291	0.35	1250	0.5	0.190
292	0.75	500	0	0.190
293	0.35	500	0.7	0.189
294	0.45	500	0.4	0.186
295	0.45	250	0.7	0.186
296	0.65	250	0.3	0.184
297	0.35	1000	0.5	0.184

298	0.25	2000	0.8	0.184
299	0.65	500	0.1	0.183
300	0.85	250	0	0.183
301	0.45	750	0.3	0.182
302	0.25	1750	0.8	0.182
303	0.65	750	0.8	0.180
304	0.25	1500	0.8	0.179
305	0.55	500	0.2	0.178
306	0.25	1250	0.8	0.175
307	0.35	750	0.5	0.175
308	0.35	2000	0.4	0.175
309	0.35	500	0.6	0.174
310	0.55	1500	0.1	0.174
311	0.55	1250	0.1	0.174
312	0.35	1750	0.4	0.174
313	0.75	250	0.1	0.173
314	0.55	250	0.4	0.173
315	0.55	1750	0.1	0.173
316	0.35	1500	0.4	0.172
317	0.45	250	0.6	0.172
318	0.55	2000	0.1	0.171
319	0.55	1000	0.1	0.171
320	0.25	2000	0.7	0.170
321	0.25	1000	0.8	0.170
322	0.35	1250	0.4	0.170
323	0.65	1000	0	0.169
324	0.65	1250	0	0.169
325	0.25	1750	0.7	0.169
326	0.45	1750	0.2	0.168
327	0.45	1500	0.2	0.168
328	0.45	2000	0.2	0.168
329	0.45	1250	0.2	0.167
330	0.25	1500	0.7	0.166
331	0.65	1500	0	0.166
332	0.65	750	0	0.166
333	0.65	1000	0.7	0.166
334	0.35	1000	0.4	0.165
335	0.45	500	0.3	0.165
336	0.55	750	0.1	0.164
337	0.65	250	0.2	0.164
338	0.45	1000	0.2	0.164
339	0.25	1250	0.7	0.163
340	0.65	1750	0	0.162
341	0.25	750	0.8	0.162
342	0.35	500	0.5	0.160
343	0.25	1000	0.7	0.159
344	0.75	250	0	0.159
345	0.65	2000	0	0.158
346	0.35	750	0.4	0.158
347	0.45	250	0.5	0.158
348	0.65	500	0	0.158
349	0.35	250	0.8	0.158
350	0.45	750	0.2	0.158
351	0.25	2000	0.6	0.157
352	0.25	1750	0.6	0.156
353	0.55	250	0.3	0.155
354	0.25	1500	0.6	0.154
355	0.35	2000	0.3	0.153
356	0.35	1750	0.3	0.153
357	0.35	1500	0.3	0.152
358	0.65	1750	0.6	0.152
359	0.55	500	0.1	0.152
360	0.25	750	0.7	0.152
361	0.25	1250	0.6	0.152
362	0.35	1250	0.3	0.151
363	0.65	250	0.1	0.150
364	0.25	500	0.8	0.149
365	0.35	250	0.7	0.149
366	0.25	1000	0.6	0.148
367	0.35	1000	0.3	0.148
368	0.35	500	0.4	0.146
369	0.45	500	0.2	0.146
370	0.45	250	0.4	0.145
371	0.25	2000	0.5	0.144
372	0.25	1750	0.5	0.143
373	0.35	750	0.3	0.143
374	0.25	1500	0.5	0.142
375	0.25	750	0.6	0.142
376	0.55	250	0.2	0.142
377	0.45	1250	0.1	0.141
378	0.25	500	0.7	0.141
379	0.55	1000	0	0.141
380	0.45	1500	0.1	0.141
381	0.25	1250	0.5	0.140

382	0.55	1250	0	0.140
383	0.35	250	0.6	0.140
384	0.45	1000	0.1	0.140
385	0.45	1750	0.1	0.139
386	0.55	750	0	0.139
387	0.65	250	0	0.139
388	0.45	2000	0.1	0.138
389	0.55	1500	0	0.138
390	0.25	1000	0.5	0.137
391	0.45	750	0.1	0.136
392	0.55	1750	0	0.135
393	0.55	500	0	0.135
394	0.35	1500	0.2	0.134
395	0.35	1750	0.2	0.134
396	0.35	500	0.3	0.133
397	0.35	2000	0.2	0.133
398	0.45	250	0.3	0.133
399	0.35	1250	0.2	0.133
400	0.25	500	0.6	0.133
401	0.55	2000	0	0.132
402	0.25	750	0.5	0.132
403	0.25	2000	0.4	0.132
404	0.35	1000	0.2	0.131
405	0.25	1750	0.4	0.131
406	0.35	250	0.5	0.131
407	0.55	250	0.1	0.131
408	0.25	1500	0.4	0.131
409	0.25	1250	0.4	0.129
410	0.45	500	0.1	0.129
411	0.35	750	0.2	0.128
412	0.25	1000	0.4	0.127
413	0.25	250	0.8	0.125
414	0.25	500	0.5	0.125
415	0.75	1750	0.4	0.123
416	0.25	750	0.4	0.123
417	0.45	250	0.2	0.123
418	0.35	250	0.4	0.123
419	0.55	250	0	0.123
420	0.35	500	0.2	0.121
421	0.45	1000	0	0.120
422	0.25	2000	0.3	0.120
423	0.25	1750	0.3	0.120

424	0.25	250	0.7	0.120
425	0.25	1500	0.3	0.119
426	0.45	750	0	0.119
427	0.45	1250	0	0.119
428	0.25	1250	0.3	0.119
429	0.45	1500	0	0.118
430	0.25	1000	0.3	0.117
431	0.35	1250	0.1	0.117
432	0.25	500	0.4	0.117
433	0.35	1500	0.1	0.117
434	0.35	1000	0.1	0.117
435	0.45	500	0	0.117
436	0.35	1750	0.1	0.116
437	0.45	1750	0	0.116
438	0.35	2000	0.1	0.116
439	0.45	250	0.1	0.115
440	0.35	250	0.3	0.115
441	0.35	750	0.1	0.115
442	0.25	250	0.6	0.115
443	0.25	750	0.3	0.114
444	0.45	2000	0	0.114
445	0.98	250	0.8	0.112
446	0.35	500	0.1	0.111
447	0.25	500	0.3	0.110
448	0.25	250	0.5	0.109
449	0.45	250	0	0.109
450	0.25	1500	0.2	0.109
451	0.25	1750	0.2	0.109
452	0.25	1250	0.2	0.109
453	0.25	2000	0.2	0.109
454	0.25	1000	0.2	0.108
455	0.35	250	0.2	0.107
456	0.25	750	0.2	0.106
457	0.35	1000	0	0.105
458	0.25	250	0.4	0.104
459	0.35	750	0	0.104
460	0.35	1250	0	0.104
461	0.35	1500	0	0.103
462	0.25	500	0.2	0.103
463	0.35	500	0	0.103
464	0.35	250	0.1	0.102
465	0.35	1750	0	0.102

466	0.35	2000	0	0.100
467	0.25	1250	0.1	0.100
468	0.25	1000	0.1	0.100
469	0.25	1500	0.1	0.100
470	0.25	250	0.3	0.100
471	0.25	1750	0.1	0.099
472	0.25	2000	0.1	0.099
473	0.25	750	0.1	0.099
474	0.35	250	0	0.098
475	0.25	500	0.1	0.097
476	0.25	250	0.2	0.095
477	0.25	1000	0	0.093
478	0.25	750	0	0.092
479	0.25	1250	0	0.092
480	0.25	500	0	0.092
481	0.25	250	0.1	0.092
482	0.25	1500	0	0.091
483	0.25	1750	0	0.091
484	0.65	2000	0.6	0.090
485	0.25	2000	0	0.090
486	0.25	250	0	0.089
487	0.75	2000	0.4	0.048
488	0.95	500	0.4	0.000
489	0.75	1000	0.5	-0.009
490	0.85	750	0.4	-0.017
491	0.85	1250	0.3	-0.024
492	0.98	1000	0.2	-0.036
493	0.95	1250	0.2	-0.080
494	0.65	1250	0.7	-0.095
495	0.75	750	0.6	-0.121
496	0.75	500	0.8	-0.148
497	0.85	1500	0.3	-0.330
498	0.65	1000	0.8	-0.342
499	0.95	750	0.3	-0.343
500	0.65	1500	0.7	-0.363
501	0.85	500	0.6	-0.375
502	0.98	500	0.4	-0.404
503	0.95	1500	0.2	-0.413
504	0.75	1250	0.5	-0.476
505	0.65	1750	0.7	-0.613
506	0.98	1250	0.2	-0.613
507	0.85	1750	0.3	-0.622
508	0.95	1750	0.2	-0.688
509	0.65	2000	0.7	-0.834
510	0.95	2000	0.2	-0.877
511	0.85	2000	0.3	-0.884
512	0.75	1500	0.5	-0.988
513	0.65	1250	0.8	-1.012
514	0.98	750	0.3	-1.058
515	0.98	1500	0.2	-1.152
516	0.85	1000	0.4	-1.170
517	0.75	750	0.7	-1.234
518	0.75	1000	0.6	-1.246
519	0.95	500	0.5	-1.480
520	0.75	1750	0.5	-1.485
521	0.98	1750	0.2	-1.544
522	0.85	750	0.5	-1.656
523	0.65	1500	0.8	-1.721
524	0.98	2000	0.2	-1.774
525	0.85	500	0.7	-1.849
526	0.75	2000	0.5	-1.939
527	0.95	1000	0.3	-2.342
528	0.65	1750	0.8	-2.405
529	0.75	1250	0.6	-2.866
530	0.85	1250	0.4	-2.874
531	0.98	500	0.5	-2.956
532	0.65	2000	0.8	-3.036
533	0.75	750	0.8	-3.627
534	0.95	750	0.4	-3.947
535	0.75	1000	0.7	-4.327
536	0.98	1000	0.3	-4.512
537	0.75	1500	0.6	-4.726
538	0.85	1500	0.4	-4.827
539	0.85	500	0.8	-4.907
540	0.95	1250	0.3	-5.230
541	0.95	500	0.6	-5.441
542	0.85	1000	0.5	-6.224
543	0.85	750	0.6	-6.239
544	0.75	1750	0.6	-6.633
545	0.85	1750	0.4	-6.778
546	0.98	750	0.4	-7.255
547	0.95	1500	0.3	-8.295
548	0.75	2000	0.6	-8.465
549	0.85	2000	0.4	-8.575

550	0.75	1250	0.7	-8.934
551	0.98	1250	0.3	-9.110
552	0.98	500	0.6	-9.677
553	0.95	1750	0.3	-11.025
554	0.75	1000	0.8	-11.236
555	0.85	1250	0.5	-13.151
556	0.95	2000	0.3	-13.198
557	0.95	1000	0.4	-13.471
558	0.98	1500	0.3	-13.605
559	0.95	500	0.7	-14.428
560	0.75	1500	0.7	-14.517
561	0.95	750	0.5	-15.404
562	0.85	750	0.7	-17.141
563	0.98	1750	0.3	-17.310
564	0.98	2000	0.3	-19.997
565	0.75	1750	0.7	-20.494
566	0.85	1000	0.6	-20.537
567	0.85	1500	0.5	-21.369
568	0.98	1000	0.4	-22.608
569	0.75	1250	0.8	-22.733
570	0.98	500	0.7	-24.601
571	0.98	750	0.5	-26.141
572	0.75	2000	0.7	-26.430
573	0.95	1250	0.4	-26.878
574	0.85	1750	0.5	-29.869
575	0.95	500	0.8	-32.206
576	0.75	1500	0.8	-37.081
577	0.85	2000	0.5	-37.933
578	0.85	750	0.8	-39.875
579	0.95	1500	0.4	-41.054
580	0.98	1250	0.4	-42.277
581	0.85	1250	0.6	-42.543
582	0.95	750	0.6	-44.196
583	0.95	1000	0.5	-47.127
584	0.75	1750	0.8	-52.964
585	0.98	500	0.8	-53.090
586	0.95	1750	0.4	-53.987
587	0.85	1000	0.7	-54.590
588	0.98	1500	0.4	-61.498
589	0.95	2000	0.4	-64.603
590	0.85	1500	0.6	-68.887
591	0.75	2000	0.8	-69.060
592	0.98	750	0.6	-70.780
593	0.98	1000	0.5	-73.467
594	0.98	1750	0.4	-77.936
595	0.95	1250	0.5	-89.209
596	0.98	2000	0.4	-90.429
597	0.85	1750	0.6	-96.345
598	0.95	750	0.7	-103.050
599	0.85	1250	0.7	-111.371
600	0.85	2000	0.6	-122.358
601	0.85	1000	0.8	-123.388
602	0.95	1000	0.6	-124.318
603	0.98	1250	0.5	-130.153
604	0.95	1500	0.5	-132.428
605	0.98	750	0.7	-155.340
606	0.95	1750	0.5	-171.749
607	0.85	1500	0.7	-178.203
608	0.98	1000	0.6	-180.789
609	0.98	1500	0.5	-184.610
610	0.95	750	0.8	-203.001
611	0.95	2000	0.5	-203.649
612	0.95	1250	0.6	-222.692
613	0.98	1750	0.5	-231.989
614	0.85	1250	0.8	-244.790
615	0.85	1750	0.7	-246.927
616	0.95	1000	0.7	-264.610
617	0.98	2000	0.5	-267.853
618	0.98	750	0.8	-288.022
619	0.98	1250	0.6	-303.941
620	0.85	2000	0.7	-310.405
621	0.95	1500	0.6	-320.917
622	0.98	1000	0.7	-361.090
623	0.85	1500	0.8	-383.141
624	0.95	1750	0.6	-410.141
625	0.98	1500	0.6	-422.130
626	0.95	1250	0.7	-450.091
627	0.95	1000	0.8	-477.357
628	0.95	2000	0.6	-480.191
629	0.85	1750	0.8	-522.227
630	0.98	1750	0.6	-526.678
631	0.98	1250	0.7	-582.412
632	0.98	2000	0.6	-602.974
633	0.98	1000	0.8	-617.452

634	0.95	1500	0.7	-634.218
635	0.85	2000	0.8	-645.770
636	0.95	1250	0.8	-780.255
637	0.98	1500	0.7	-799.078
638	0.95	1750	0.7	-802.104
639	0.95	2000	0.7	-927.590
640	0.98	1250	0.8	-969.468
641	0.98	1750	0.7	-992.204
642	0.95	1500	0.8	-1084.839
643	0.98	2000	0.7	-1124.301
644	0.98	1500	0.8	-1323.739
645	0.95	1750	0.8	-1361.783
646	0.95	2000	0.8	-1555.051
647	0.98	1750	0.8	-1636.593
648	0.98	2000	0.8	-1833.526

Table S3. Local climatic data from KNYC, Central Park, for 11-12 September.

Year	Time (EDT)	Temp.	Dew Point	Humidity	Pressure	Visibility	Wind Dir	Wind Speed	Precip	Conditions
2008	7:51 PM	17.78	12.22	54%	1026	16.09	SE	9.33	N/A	Clear
	8:51 PM	18.28	12.22	63%	1027	16.09	SSE	Calm	N/A	Clear
	9:51 PM	18.28	12.22	63%	1026	16.09	Variable	7.40	N/A	Clear
	10:51 PM	18.89	12.22	68%	1026	16.09	Variable	7.40	N/A	Clear
	11:51 PM	18.28	12.78	68%	1026	16.09	Variable	9.33	N/A	Scattered Clouds
	12:51 AM	18.28	12.22	68%	1025	16.09	Variable	11.10	N/A	Overcast
	1:51 AM	18.89	12.22	73%	1025	16.09	SSE	5.63	N/A	Scattered Clouds
	2:51 AM	18.28	12.78	70%	1024	16.09	Variable	7.40	N/A	Scattered Clouds
	3:51 AM	18.89	12.22	73%	1024	16.09	Variable	7.40	N/A	Clear
	4:51 AM	18.89	12.78	73%	1023	16.09	Variable	5.63	N/A	Clear
	5:51 AM	18.89	12.22	73%	1024	16.09	Variable	Calm	N/A	Clear
2010	7:51 PM	20.61	11.11	54%	1015	16.09	SE	13.04	N/A	Clear
	8:51 PM	19.39	12.22	63%	1016	16.09	SSE	13.04	N/A	Clear
	9:51 PM	20.00	12.78	63%	1017	16.09	Variable	11.10	N/A	Clear
	10:51 PM	19.39	13.28	68%	1017	16.09	Variable	9.33	N/A	Clear
	11:51 PM	19.39	13.28	68%	1018	16.09	Variable	5.63	N/A	Scattered Clouds
	12:51 AM	19.39	13.28	68%	1018	16.09	Variable	9.33	N/A	Overcast
	1:51 AM	18.28	13.28	73%	1017	16.09	SSE	13.04	N/A	Scattered Clouds
	2:51 AM	18.89	13.28	70%	1017	16.09	Variable	5.63	N/A	Scattered Clouds
	3:51 AM	18.28	13.28	73%	1016	16.09	Variable	9.33	N/A	Clear
	4:51 AM	18.28	13.28	73%	1017	16.09	Variable	11.10	N/A	Clear
	5:51 AM	17.78	12.78	73%	1017	16.09	Variable	9.33	N/A	Clear
2012	7:51 PM	18.89	6.72	55%	1025	16.09	Variable	5.63	N/A	Mostly Cloudy
	8:51 PM	18.89	6.11	59%	1025	16.09	North	Calm	N/A	Clear
	9:51 PM	18.28	8.28	61%	1025	16.09	SW	Calm	N/A	Clear
	10:51 PM	18.28	9.39	63%	1025	16.09	Variable	5.63	N/A	Scattered Clouds
	11:51 PM	18.28	8.89	67%	1025	16.09	Variable	5.63	N/A	Clear
	12:51 AM	18.28	8.28	67%	1026	16.09	SW	7.40	N/A	Clear
	1:51 AM	17.78	10.00	65%	1026	16.09	SW	Calm	N/A	Clear
	2:51 AM	17.22	8.89	69%	1026	16.09	Variable	Calm	N/A	Clear
	3:51 AM	17.22	9.39	69%	1026	16.09	Variable	Calm	N/A	Mostly Cloudy

	4:51 AM	16.11	10.00	71%	1027	16.09	SW	5.63	N/A	Partly Cloudy
	5:51 AM	15.61	11.11	74%	1011	16.09	Variable	Calm	N/A	Clear
2013	7:51 PM	31.11	21.11	55%	1017	12.87	Variable	5.63	N/A	Mostly Cloudy
	8:51 PM	30.00	21.11	59%	1017	12.87	North	7.24	N/A	Clear
	9:51 PM	29.39	21.11	61%	1016	14.48	SW	11.10	N/A	Clear
	10:51 PM	28.89	21.11	63%	1017	12.87	Variable	7.40	N/A	Scattered Clouds
	11:51 PM	27.78	21.11	67%	1016	12.87	Variable	9.33	N/A	Clear
	12:51 AM	27.78	21.11	67%	1015	12.87	SW	9.33	N/A	Clear
	1:51 AM	27.22	20.00	65%	1014	12.87	SW	9.33	N/A	Clear
	2:51 AM	26.11	20.00	69%	1014	11.27	Variable	7.40	N/A	Clear
	3:51 AM	26.11	20.00	69%	1014	11.27	Variable	5.63	N/A	Mostly Cloudy
	4:51 AM	25.61	20.00	71%	1014	11.27	SW	5.63	N/A	Partly Cloudy
	5:51 AM	25.00	20.00	74%	1014	11.27	Variable	9.33	N/A	Clear
2014	7:51 PM	26.11	19.39	54%	1012	16.09	Calm	5.63	N/A	Scattered Clouds
	8:51 PM	26.11	19.39	57%	1012	16.09	Variable	Calm	N/A	Clear
	9:51 PM	26.11	19.39	57%	1013	16.09	Calm	11.10	N/A	Clear
	10:51 PM	24.39	15.61	57%	1014	16.09	Calm	5.63	N/A	Clear
	11:51 PM	22.22	12.78	66%	1015	16.09	Calm	7.40	N/A	Clear
	12:51 AM	21.11	11.72	71%	1015	16.09	Calm	13.04	N/A	Clear
	1:51 AM	20.00	11.72	73%	1016	16.09	Calm	9.33	N/A	Clear
	2:51 AM	19.39	11.11	78%	1016	16.09	NE	7.40	N/A	Clear
	3:51 AM	18.28	11.11	81%	1018	16.09	Calm	5.63	N/A	Clear
	4:33 AM	17.78	10.61	84%	1017	16.09	Calm	9.33	N/A	Clear
	4:51 AM	17.78	10.61	81%	1018	16.09	West	7.40	N/A	Clear
	5:51 AM	17.22	10.00	37%	0	0.00	Variable	0.00	N/A	Clear
2015	7:51 PM	24.39	14.39	54%	1009	16.09	Calm	Calm	N/A	Scattered Clouds
	8:51 PM	23.89	15.00	57%	1009	16.09	Variable	5.63	N/A	Clear
	9:51 PM	23.89	15.00	57%	1009	16.09	Calm	Calm	N/A	Clear
	10:51 PM	23.89	15.00	57%	1010	16.09	Calm	Calm	N/A	Clear
	11:51 PM	23.28	16.72	66%	1010	16.09	Calm	Calm	N/A	Clear
	12:51 AM	22.78	17.22	71%	1010	16.09	Calm	Calm	N/A	Clear
	1:51 AM	22.22	17.22	73%	1009	16.09	Calm	Calm	N/A	Clear
	2:51 AM	21.72	17.78	78%	1009	16.09	NE	5.63	N/A	Clear

	3:51 AM	21.72	18.28	81%	1009	16.09	Calm	Calm	N/A	Clear
	4:51 AM	21.11	18.28	84%	1009	16.09	Calm	Calm	N/A	Clear
	5:51 AM	21.11	17.78	81%	1010	16.09	West	5.63	N/A	Clear
2016	7:51 PM	24.39	8.89	37%	1019	16.09	Variable	5.63	N/A	Clear
	8:51 PM	23.89	8.89	38%	1020	16.09	Variable	7.40	N/A	Clear
	9:51 PM	22.22	8.28	41%	1020	16.09	Variable	5.63	N/A	Clear
	10:51 PM	21.11	7.78	42%	1021	16.09	Variable	7.40	N/A	Clear
	11:51 PM	20.61	7.78	44%	1021	16.09	NNW	9.33	N/A	Clear
	12:51 AM	20.00	7.78	45%	1022	16.09	Variable	7.40	N/A	Clear
	1:51 AM	19.39	7.78	47%	1022	16.09	Variable	7.40	N/A	Clear
	2:51 AM	18.89	7.78	48%	1022	16.09	ENE	11.10	N/A	Clear
	3:51 AM	18.28	7.22	48%	1022	16.09	ENE	13.04	N/A	Clear
	4:51 AM	16.72	8.28	58%	1023	16.09	East	13.04	N/A	Clear
	5:51 AM	17.22	8.28	56%	1023	16.09	ENE	9.33	N/A	Clear

Table S4. METARS data from KEWR, Newark Liberty International Airport, for 11-12 September. UTC refers to Coordinated Universal Time.

Year	UTC	Full METAR
2008	23:51	18008KT 10SM FEW070 SCT250 20/12 A3031 RMK AO2 SLP263 T02000117 10228 20200 53001
	00:51	19006KT 10SM BKN060 BKN250 19/12 A3031
	01:51	19006KT 10SM BKN060 BKN250 19/12 A3032 RMK AO2 SLP266 T01940122
	02:51	18006KT 10SM SCT055 BKN250 19/12 A3031 RMK AO2 SLP262 T01890117 58000
	03:51	19005KT 10SM BKN060 BKN250 19/12 A3030 RMK AO2 SLP259 T01890117
	04:51	20006KT 10SM BKN060 19/12 A3029 RMK AO2 SLP257 T01890117 402280161
	04:58	19006KT 10SM SCT055 OVC070 19/12 A3027 RMK AO2 SLP250 T01890122 10200 20189 58012
	05:13	19004KT 10SM BKN050 OVC070 19/12 A3026 RMK AO2 SLP245 T01890117
	05:51	20007KT 10SM OVC048 19/12 A3025 RMK AO2 SLP242 T01890117
	06:51	21005KT 10SM OVC044 19/12 A3024 RMK AO2 SLP238 T01890122 56013
	07:51	20005KT 10SM FEW030 OVC042 19/12 A3022 RMK AO2 SLP232 T01890122
2010	23:51	13007KT 10SM FEW070 BKN250 22/12 A2998 RMK AO2 SLP150 T02170122 10278 20211 53010
	00:51	13007KT 10SM BKN250 21/13 A3000 RMK AO2 SLP157 T02110128
	01:51	17005KT 10SM BKN250 20/13 A3002 RMK AO2 SLP166 T02000128
	02:51	17004KT 10SM BKN250 20/13 A3004 RMK AO2 SLP170 T02000133 51020
	03:51	16005KT 10SM FEW035 BKN250 20/13 A3004 RMK AO2 SLP172 T02000133
	04:51	14007KT 10SM BKN035 BKN250 20/14 A3004 RMK AO2 SLP171 T02000144 402780144
	04:58	14007KT 10SM BKN027 BKN037 20/14 A3004 RMK AO2
	05:13	14007KT 10SM SCT027 BKN035 20/14 A3004 RMK AO2
	05:51	14007KT 10SM FEW027 SCT035 19/14 A3004 RMK AO2 SLP171 T01940139 10217 20194 51001
	06:51	13006KT 10SM FEW037 19/14 A3003 RMK AO2 SLP168 T01940139
	07:51	11005KT 10SM FEW037 SCT090 BKN250 19/14 A3000 RMK AO2 SLP159 T01940144
	08:51	11007KT 10SM FEW027 SCT110 BKN250 19/13 A3001 RMK AO2 SLP162 T01890133 55009
	09:51	11004KT 10SM FEW027 BKN110 BKN250 19/13 A3001 RMK AO2 SLP162 T01890133
2012	23:51	25006KT 10SM SCT260 22/08 A3024 RMK AO2 SLP240 T02170083 10250 20211 53006
	00:51	25005KT 10SM FEW260 21/08 A3026 RMK AO2 SLP248 T02110083
	01:51	24003KT 10SM FEW250 19/09 A3027 RMK AO2 SLP250 T01940089
	02:51	25006KT 10SM FEW250 19/09 A3027 RMK AO2 SLP251 T01890094 51011
	03:51	21003KT 10SM CLR 18/09 A3028 RMK AO2 SLP252 T01780094
	04:51	23005KT 10SM CLR 16/10 A3028 RMK AO2 SLP254 T01610100 402500117

	05:51	23004KT 10SM CLR 16/10 A3029 RMK AO2 SLP257 T01560100 10217 20156 53006
	06:51	00000KT 10SM CLR 16/11 A3030 RMK AO2 SLP258 T01560106
	07:51	22004KT 10SM CLR 14/11 A3030 RMK AO2 SLP258 T01440106
	08:51	27003KT 10SM CLR 15/11 A3031 RMK AO2 SLP262 T01500106 53004
	09:51	00000KT 10SM FEW250 14/11 A3032 RMK AO2 SLP266 T01390106
2013	23:51	22011KT 10SM FEW050 SCT200 BKN250 31/21 A3001 RMK AO2 SLP162 T03110211 10356 20311 53012
	00:51	19008KT 10SM FEW015 SCT050 OVC250 31/22 A3002 RMK AO2 SLP165 T03060217
	01:51	20010KT 10SM OVC250 29/22 A3001 RMK AO2 SLP162 T02940217
	02:51	22006KT 10SM SCT038 OVC250 29/22 A3001 RMK AO2 SLP163 T02890217 51001
	03:51	22009KT 10SM SCT045 OVC250 28/22 A2999 RMK AO2 SLP156 T02780217
	04:51	20009KT 9SM FEW050 OVC250 27/22 A2997 RMK AO2 SLP148 T02670217 403560239
	05:51	20008KT 9SM BKN250 26/21 A2995 RMK AO2 SLP142 T02610211 10311 20261 56021
	06:51	19006KT 9SM BKN250 26/21 A2995 RMK AO2 SLP141 T02560211
	07:51	20008KT 8SM SCT055 BKN250 25/21 A2994 RMK AO2 SLP139 T02500211
	08:51	21006KT 8SM SCT055 BKN250 24/21 A2994 RMK AO2 SLP136 T02440211 58005
	09:51	21006KT 7SM FEW055 BKN250 24/21 A2994 RMK AO2 SLP136 T02390211
2014	23:51	25007KT 10SM FEW040 SCT120 SCT250 27/20 A2985 RMK AO2 SLP107 T02720200 10300 20272 53009
	00:51	26007KT 10SM FEW040 SCT120 SCT250 27/20 A2987 RMK AO2 SLP114 T02670200
	01:51	29010KT 10SM FEW045 SCT250 26/20 A2989 RMK AO2 SLP121 T02610200
	02:51	33013G19KT 10SM FEW045 SCT250 24/17 A2992 RMK AO2 SLP131 T02440167 53024
	03:51	35014G19KT 10SM FEW045 SCT250 22/14 A2995 RMK AO2 SLP141 T02220139
	04:51	34009KT 10SM FEW050 SCT250 21/12 A2997 RMK AO2 SLP147 T02060122 403000189
	05:51	34010G19KT 10SM FEW250 20/12 A2997 RMK AO2 SLP149 T02000122 10272 20200 51018
	06:51	34012KT 10SM FEW050 SCT250 19/12 A2999 RMK AO2 SLP154 T01890122
	07:51	34013KT 10SM FEW025 SCT050 SCT250 18/12 A3002 RMK AO2 SLP164 T01830117
	08:51	34009KT 10SM FEW025 SCT050 SCT250 17/11 A3003 RMK AO2 SLP168 T01720111 51020
	09:51	34012G18KT 10SM FEW025 17/11 A3005 RMK AO2 SLP175 T01670106
2015	23:51	VRB04KT 10SM FEW045 SCT250 27/16 A2978 RMK AO2 SLP084 T02670156 10289 20256 53012
	00:51	00000KT 10SM FEW045 SCT250 25/17 A2980 RMK AO2 SLP091 T02500167
	01:51	11004KT 10SM FEW045 SCT250 24/17 A2981 RMK AO2 SLP093 T02440167
	02:51	00000KT 10SM FEW045 SCT250 23/19 A2981 RMK AO2 SLP095 T02330189 51011
	03:51	00000KT 10SM FEW050 23/19 A2982 RMK AO2 SLP096 T02280189
	04:51	17003KT 10SM FEW050 22/18 A2982 RMK AO2 SLP096 T02170183 402890189

	05:51	15003KT 10SM FEW050 21/18 A2981 RMK AO2 SLP094 T02110183 10267 20206 58001
	06:51	19004KT 10SM FEW050 20/18 A2981 RMK AO2 SLP093 T02000178
	07:51	18003KT 10SM FEW050 SCT250 20/18 A2981 RMK AO2 SLP094 T02000183
	08:51	00000KT 10SM FEW050 SCT250 19/18 A2981 RMK AO2 SLP094 T01940178 56000
	09:51	00000KT 10SM SCT050 SCT250 19/17 A2982 RMK AO2 SLP098 T01890172
2016	23:51	32013KT 10SM BKN250 25/08 A3008 RMK AO2 SLP185 T02500078 10300 20250 53023
	00:51	32012KT 10SM BKN250 24/07 A3011 RMK AO2 SLP195 T02390072
	01:51	34011KT 10SM BKN250 23/07 A3013 RMK AO2 SLP202 T02280072
	02:51	35009KT 10SM BKN250 22/08 A3015 RMK AO2 SLP208 T02170078 51023
	03:51	34011KT 10SM SCT250 21/08 A3016 RMK AO2 SLP212 T02060078
	04:51	36008KT 10SM SCT250 19/08 A3017 RMK AO2 SLP217 T01890078 403000189
	05:51	02007KT 10SM SCT250 17/08 A3017 RMK AO2 SLP216 T01670078 10250 20167 50008
	06:51	01007KT 10SM SCT250 17/08 A3018 RMK AO2 SLP220 T01670078
	07:51	02007KT 10SM FEW250 15/08 A3019 RMK AO2 SLP222 T01500078
	08:51	01006KT 10SM CLR 14/08 A3020 RMK AO2 SLP227 T01440083 53011
	09:51	36007KT 10SM FEW250 16/09 A3022 RMK AO2 SLP231 T01610089

Full details of the codes and abbreviations for METARS data are available from http://www.ofcm.gov/publications/fmh/FMH1/FMH1.pdf.

Model Information and Additional Calculations

Contents

This document presents detailed results for all non-simulation analyses, focusing on linear model output and diagnostics.

```
library(mgcv)      # v 1.8-17 - gam
library(regr0)     # v 1.0-5 - logst
library(lattice)
library(Hmisc)
library(ggplot2)
library(cowplot)
```

Note on transformations: We use the *logst* function in the *regr0* package to log-transform our data when necessary. This function is equivalent to a log_{10} transformation for all but the smallest values, which are scaled such that the transformation yields finite values (e.g. because $log_{10}(0)$ is undefined). We chose this option because, unlike adding an arbitrary constant value of 1 to all observations, this method of scaling small values is determined by the distribution of the data, and importantly it only modifies the smallest observations, leaving all others unchanged.

Peak effects

The following models include one data point for each continous period of illumination or darkness: the maximum value observed during that period.

Standardized peak density

Standardized peak density is defined as:

$$\frac{max(\eta_{0-0.5km}) - mean(\eta_{2-20km})}{sd(\eta_{2-20km})}$$

Where $\eta_{0-0.5km}$ is the set of bird density values within 0.5 km of the Tribute and η_{2-20km} is the set of bird density values between 2-20 km from the Tribute.

In all cases, we compare three models with the following parametric effects using AIC:

1. $light + year + light \times year$
2. $light + year$
3. $light$

Here, *light* is a two-level categorical variable describing whether the Tribute was illuminated or not, and *year* is a four-level categorical variable describing the year in which that observation occurred.

We used the model with the lowest AIC score, unless there was a difference of less than 1 AIC unit separating the models. In this case, we used the model with the fewest parametric effects.

0.5º elevation angle

```
m1 = gam(logst(val)~light*year,data=light.df.g %>% filter(elev==1 & the.type=="max.peak.std"))
m2 = gam(logst(val)~light+year,data=light.df.g %>% filter(elev==1 & the.type=="max.peak.std"))
m3 = gam(logst(val)~light,data=light.df.g %>% filter(elev==1 & the.type=="max.peak.std"))
AIC(m1,m2,m3)
```

```
##    df      AIC
## m1 11 116.7996
## m2  7 120.8748
## m3  3 116.3087
```

```
bm = m3
```

The best model is model 3, which includes *light* only.

```
summary(bm)
```

```
##
## Family: gaussian
## Link function: identity
##
## Formula:
## logst(val) ~ light
##
## Parametric coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept)  -0.2890     0.1555  -1.858    0.069 .
## light         1.1487     0.2014   5.703 6.32e-07 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
##
## R-sq.(adj) =  0.382   Deviance explained = 39.4%
## GCV = 0.52829  Scale est. = 0.50797   n = 52
```

The main effect of *light* is 1.149, which can be back-transformed as $10^{1.149}$ and interpreted as a multiplicative factor. In other words, the model indicates that the maximum standardized peak bird density observed during an illuminated period was $10^{1.149} = 14$ times greater than during dark periods, on average.

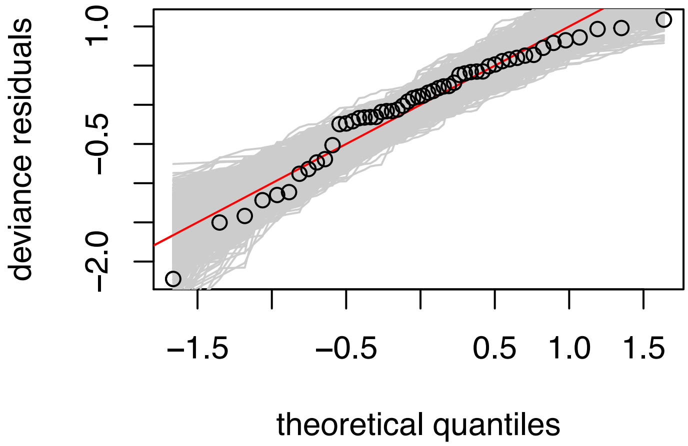
Results summarized for the main text:

```
res = summary(bm)$p.table
res = cbind(res,Factor=10^(res[,"Estimate"]))
# Effect of light after exponentiating the coefficient to get multiplicative factor
print.model.summary(res[2,5],res[2,3],res[2,4],units="x",effect.word="factor")
```

```
## [1] "factor = 14x, t = 5.70, P < 0.0001"
```

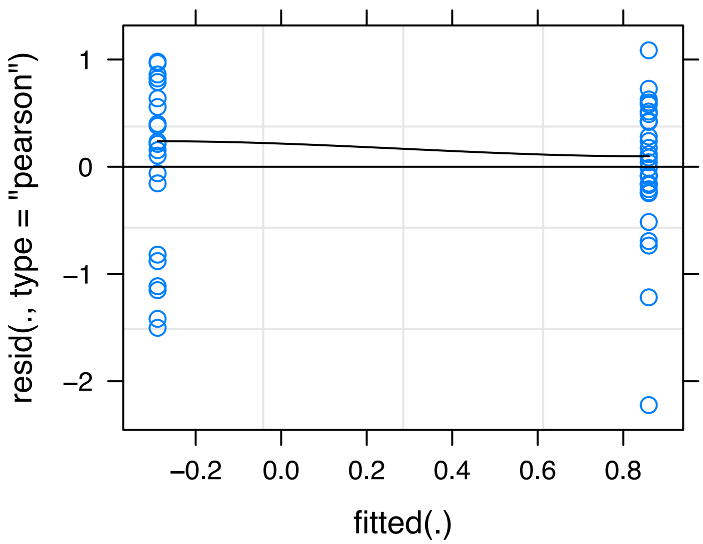
We now examine two important model diagnostic plots. The first is a standard quantile-quantile (or 'qq') plot, showing the distribution of the residuals compared to the quantiles of a normal distribution. Also plotted are the distributions of 1000 datasets simulated under the model, to show how much variation is expected if all assumptions are fulfilled. In this instance, all points are well within the gray lines; there is no evidence for a deviation from this assumption.

```
qq.gam(bm,rep=1000,pch=1,level=1)
```



Next, we examine a Tukey-Anscombe plot, the model residuals vs. the fitted values. There doesn't appear to be significant structure left in the data, and the variance of the residuals appears constant throughout, so there is no evidence for any deviation.

```
plot.lme(bm,type=c("p","smooth"),col.line="black")
```



1.5º elevation angle

This section runs the same models as the previous section, but with data from the high-altitude radar sweep (~1.5º elevation angle).

```
m1 = gam(logst(val)~light*year,
         data=light.df.g %>% filter(elev==1.5 & the.type=="max.peak.std"))
m2 = gam(logst(val)~light+year,
         data=light.df.g %>% filter(elev==1.5 & the.type=="max.peak.std"))
m3 = gam(logst(val)~light,
         data=light.df.g %>% filter(elev==1.5 & the.type=="max.peak.std"))
AIC(m1,m2,m3)
```

```
##    df      AIC
## m1 11 116.2694
## m2  7 113.1496
```

```
## m3  3 111.4823
```

```
bm = m3
```

Again, the best model is model 3, which includes *light* only.

```
summary(bm)
```

```
##
## Family: gaussian
## Link function: identity
##
## Formula:
## logst(val) ~ light
##
## Parametric coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept)  -0.6449     0.1365  -4.723  1.8e-05 ***
## light         0.5859     0.1802   3.251  0.00202 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
##
## R-sq.(adj) =  0.153   Deviance explained = 16.9%
## GCV = 0.44529  Scale est. = 0.4288    n = 54
```

Here there is one main effect of *light*, and the model indicates that maximum standardized peak bird densities were $10^{0.58} = 3.9$ times higher during illuminated periods, on average.

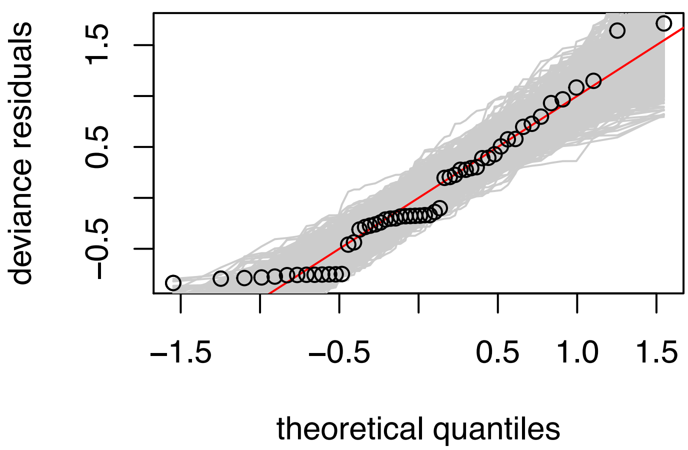
Results for the main text:

```
res = summary(bm)$p.table
res = cbind(res,Factor=10^(res[,"Estimate"]))
# Effect of light after exponentiating the coefficient to get multiplicative factor
print.model.summary(res[2,5],res[2,3],res[2,4],units="x",effect.word="factor")
```

```
## [1] "factor = 3.9x, t = 3.25, P = 0.0020"
```

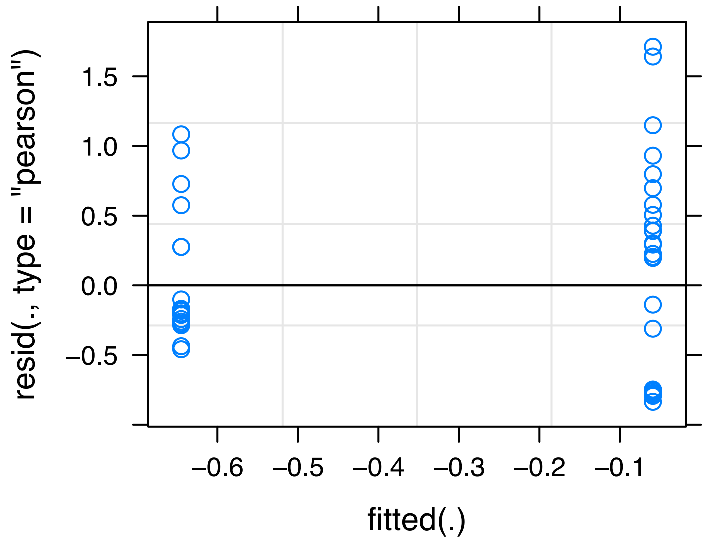
All points are within the gray simluated lines.

```
qq.gam(bm,rep=1000,pch=1,level=1)
```



The Tukey-Anscombe plot suggests that the variance may be increasing, but the difference is not extreme.

```
plot.lme(bm,type=c("p","r"),col.line="black")
```



Max number of birds within 500 m of the TiL

This section performs the same analysis as the previous section, except the response variable is the maximum number of birds detected within 500 m of the TiL during a continuous illuminated/dark period.

0.5º elevation angle

```
m1 = gam(logst(val)~light*year,data=light.df.g %>% filter(elev==1 & the.type=="max.nbirds"))
m2 = gam(logst(val)~light+year,data=light.df.g %>% filter(elev==1 & the.type=="max.nbirds"))
m3 = gam(logst(val)~light,data=light.df.g %>% filter(elev==1 & the.type=="max.nbirds"))
AIC(m1,m2,m3)
```

```
##    df      AIC
## m1 11 83.99201
## m2  7 78.16597
## m3  3 94.05718
```

```
bm = m2
```

The best model is model 2, which includes the *light* and *year* but not their interaction.

```
summary(bm)
```

```
##
## Family: gaussian
## Link function: identity
##
## Formula:
## logst(val) ~ light + year
##
## Parametric coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept)  2.08254    0.15619  13.333  < 2e-16 ***
## light        0.52534    0.13506   3.890 0.000321 ***
## year2012    -0.21004    0.23543  -0.892 0.376952
## year2013    -0.01684    0.20056  -0.084 0.933460
## year2015     0.70110    0.17818   3.935 0.000279 ***
## year2016     0.07999    0.22361   0.358 0.722184
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
##
## R-sq.(adj) =  0.406   Deviance explained = 46.4%
## GCV = 0.25699  Scale est. = 0.22734   n = 52
```

Here there is one main effect of *light*, and the model indicates that maximum number of birds within 500 m of the TiL was $10^{0.53} = 3.4$ times higher during illuminated periods, on average.

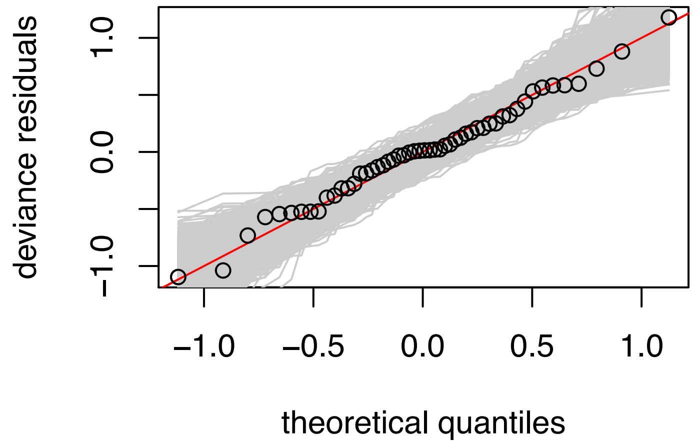
Results for the main text:

```
res = summary(bm)$p.table
res = cbind(res,Factor=10^(res[,"Estimate"]))
# Effect of light after exponentiating the coefficient to get multiplicative factor
print.model.summary(res[2,5],res[2,3],res[2,4],units="x",effect.word="factor")
```

```
## [1] "factor = 3.4x, t = 3.89, P = 0.0003"
```

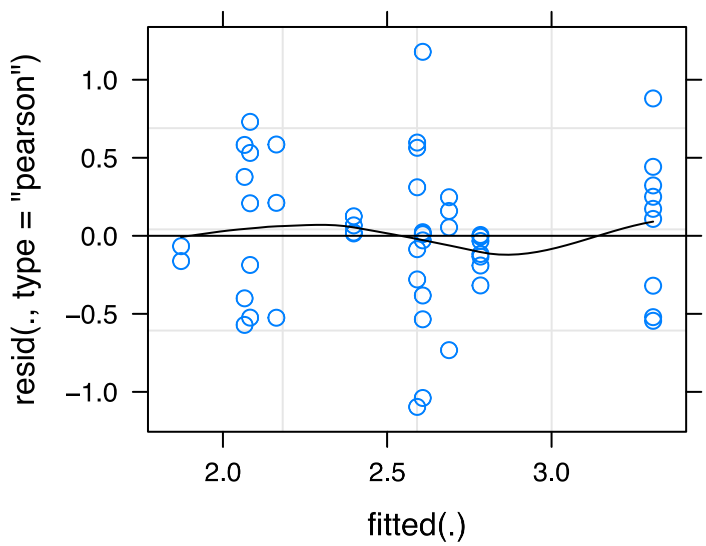
No evidence for any deviation.

```
qq.gam(bm,rep=1000,pch=1,level=1)
```



Negligible structure in the residuals.

```
plot.lme(bm,type=c("p","smooth"),col.line="black")
```



1.5º elevation angle

This section runs the same models as the previous section, but with data from the high-altitude radar scan.

```
m1 = gam(logst(val)~light*year,data=light.df.g %>% filter(elev==1.5 & the.type=="max.nbirds"))
m2 = gam(logst(val)~light+year,data=light.df.g %>% filter(elev==1.5 & the.type=="max.nbirds"))
m3 = gam(logst(val)~light,data=light.df.g %>% filter(elev==1.5 & the.type=="max.nbirds"))
AIC(m1,m2,m3)
```

```
##    df      AIC
## m1 11 141.5482
## m2  7 136.9647
## m3  3 141.4726
```

```
bm = m2
```

The best model is model 2, which includes *light* and *year*, but not their interaction.

```r
summary(bm)
```

```
##
## Family: gaussian
## Link function: identity
##
## Formula:
## logst(val) ~ light + year
##
## Parametric coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept) -0.05014    0.26089  -0.192  0.84840
## light        0.51996    0.22204   2.342  0.02339 *
## year2012    -0.52410    0.39566  -1.325  0.19156
## year2013    -0.69052    0.33707  -2.049  0.04599 *
## year2015    -0.06806    0.29279  -0.232  0.81717
## year2016    -1.07497    0.37580  -2.861  0.00625 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
##
## R-sq.(adj) =  0.191   Deviance explained = 26.7%
## GCV = 0.72239  Scale est. = 0.64213   n = 54
```

Here there is one main effect of *light*, and the model indicates that maximum number of birds within 500 m of the TiL was $10^{0.52} = 3.3$ times higher during illuminated periods, on average.

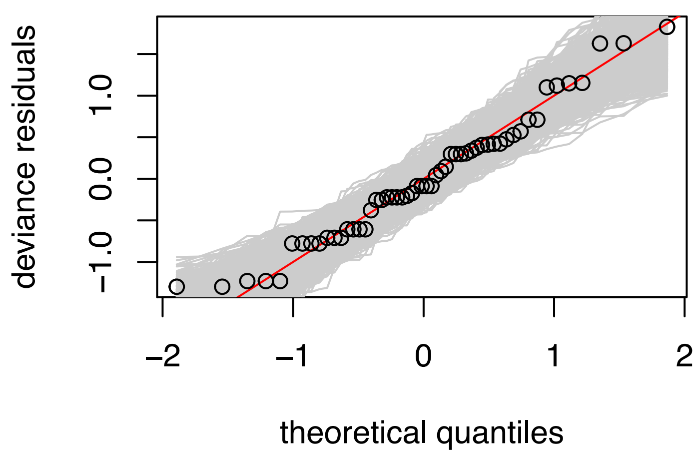
Results for the main text:

```r
res = summary(bm)$p.table
res = cbind(res,Factor=10^(res[,"Estimate"]))
# Effect of light after exponentiating the coefficient to get multiplicative factor
print.model.summary(res[2,5],res[2,3],res[2,4],units="x",effect.word="factor")
```

```
## [1] "factor = 3.3x, t = 2.34, P = 0.0234"
```

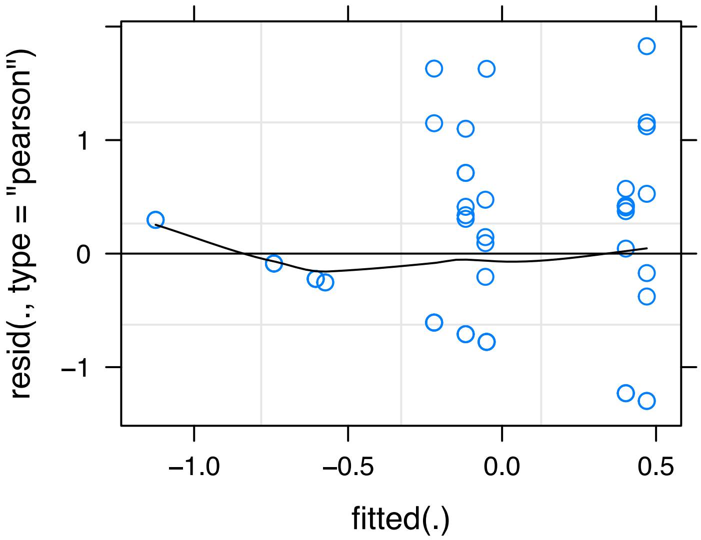
No evidence for any deviation.

```r
qq.gam(bm,rep=1000,pch=1,level=1)
```



The variance may be increasing, although the sample size of points at low x-values is small. No other structure is apparent in the data, which have already been log-transformed. Furthermore, if anything, this would likely make our test conservative.

```
plot.lme(bm,type=c("p","smooth"),col.line="black")
```



Average effects

The following models include all data points (not just one per light/dark period). To account for any autocorrelation in the data, we introduce two additional predictor variables as smooth terms: time of night (*TIME*) and baseline bird density (*BIRD_DENSITY*). These smooth terms account for variation explained by temporal changes in bird numbers through the night and as a result of changes in baseline bird density—separate from any effect of the Tribute in Light (*LIGHT*).

Numbers of birds

0.5º elevation angle

We test for effect of light on the total number of birds present in the cylinder with radius 500 m and height 4.5 km, calculated from the 0.5º elevation angle sweep.

```
# 'stationary.radar.model.light' is a custom function to construct the necessary models
# and compare AIC values
n.birds.e1.model = stationary.radar.model.light(response.name="logst(n.birds.cyl.e1)",
                    the.data=dt1,elev="e1")
```

```
##                       df       AIC
## mod.light      23.37065  98.69452
## mod.light.year 24.82408 101.31629
## mod.interact   29.16755 105.87983
```

```
bm = n.birds.e1.model
```

The best model includes *light* only.

```
summary(bm)
```

```
##
## Family: gaussian
## Link function: identity
##
## Formula:
## eval(parse(text = response.name)) ~ eval(LIGHT) + s(as.numeric(eval(TIME)),
##     by = year) + s(eval(BIRD_DENSITY), by = year)
##
## Parametric coefficients:
##                 Estimate Std. Error t value Pr(>|t|)
## (Intercept)  -718.92637  230.15140  -3.124  0.00207 **
## eval(LIGHT)1    0.52562    0.05628   9.339  < 2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Approximate significance of smooth terms:
##                                    edf Ref.df      F  p-value
## s(as.numeric(eval(TIME))):year2010 1.034  1.057  8.904  0.00238 **
## s(as.numeric(eval(TIME))):year2012 1.026  1.051  9.156  0.00230 **
## s(as.numeric(eval(TIME))):year2013 1.848  1.968  5.132  0.00967 **
## s(as.numeric(eval(TIME))):year2015 1.000  1.000  9.802  0.00201 **
## s(as.numeric(eval(TIME))):year2016 1.000  1.000  9.790  0.00203 **
## s(eval(BIRD_DENSITY)):year2010     6.049  6.942 14.895 3.52e-16 ***
```

```
## s(eval(BIRD_DENSITY)):year2012     1.000  1.000  0.000  0.99561
## s(eval(BIRD_DENSITY)):year2013     1.919  2.017 36.520 1.34e-13 ***
## s(eval(BIRD_DENSITY)):year2015     3.307  4.055 21.332 5.33e-15 ***
## s(eval(BIRD_DENSITY)):year2016     2.187  2.583 19.321 1.02e-05 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## R-sq.(adj) =  0.806   Deviance explained = 82.6%
## GCV = 0.094149  Scale est. = 0.084072  n = 209
```

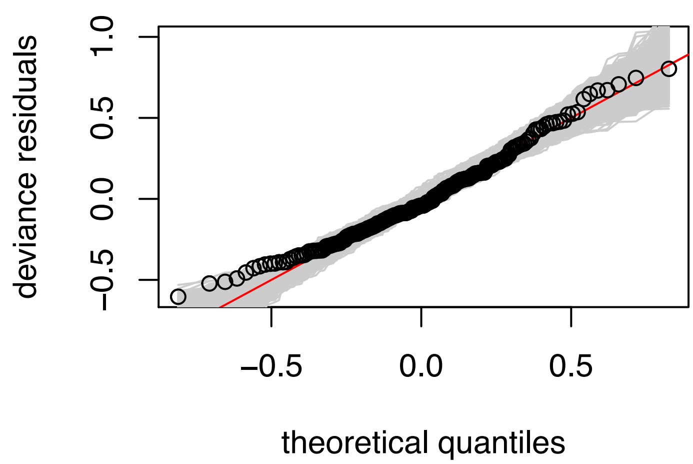
Results for the main text:

```
res = summary(bm)$p.table
res = cbind(res,Factor=10^(res[,"Estimate"]))
# Exponentiating the coefficient to get multiplicative factor
print.model.summary(res[2,5],res[2,3],res[2,4],units="x",effect.word="factor")
```

```
## [1] "factor = 3.4x, t = 9.34, P < 0.0001"
```

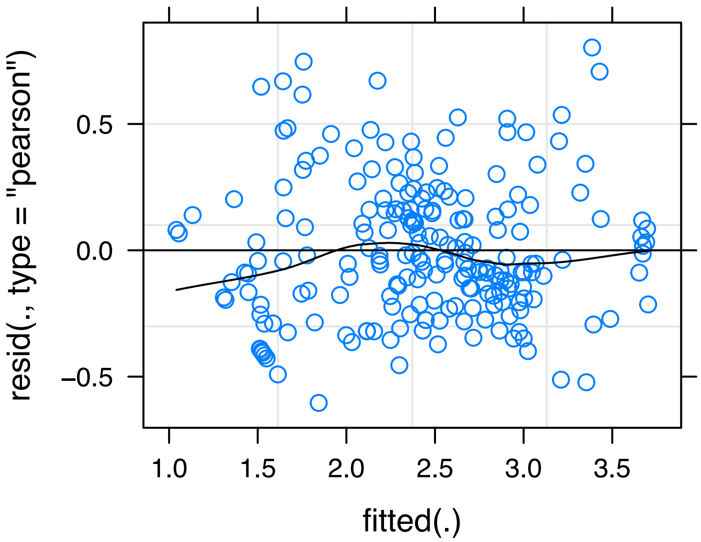
No evidence of any deviation; all points within the bounds of the simulated datasets.

```
qq.gam(bm,rep=1000,pch=1,level=1)
```



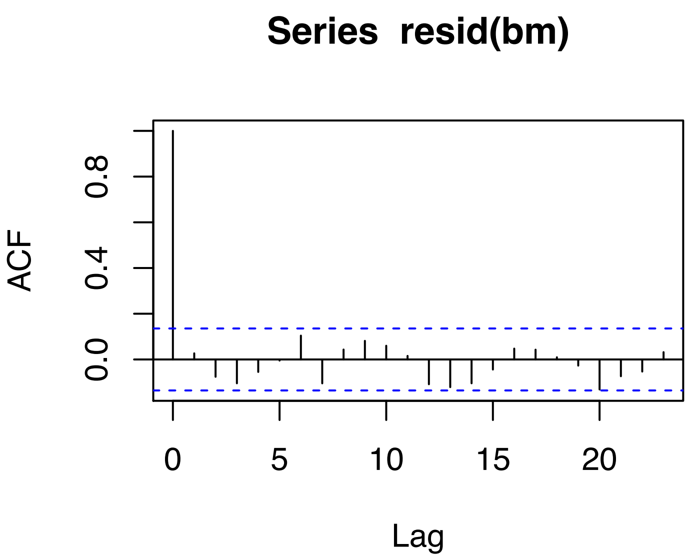
No evidence of any deviation or structure.

```
plot.lme(bm,type=c("p","smooth"),col.line="black")
```



No autocorrelation of residuals.

```r
acf(resid(bm))
```



1.5º elevation angle

```r
n.birds.e2.model = stationary.radar.model.light("logst(n.birds.cyl.e2)",dt2,elev="e2")
```

```
##                        df      AIC
## mod.light.year 26.01437 275.0162
## mod.interact   29.86173 275.4296
## mod.light      20.52622 283.4821
```

```r
bm = n.birds.e2.model
```

The best model includes *light* and *year* but not their interaction.

```r
summary(bm)
```

```
##
```

```
## Family: gaussian
## Link function: identity
##
## Formula:
## eval(parse(text = response.name)) ~ eval(LIGHT) + year + s(as.numeric(eval(TIME)),
##     by = year) + s(eval(BIRD_DENSITY), by = year)
##
## Parametric coefficients:
##                Estimate Std. Error t value Pr(>|t|)
## (Intercept)  -8583.0276  2640.8272  -3.250 0.001367 **
## eval(LIGHT)1     0.2875     0.0823   3.493 0.000595 ***
## year2012      5897.7775  2897.5004   2.035 0.043207 *
## year2013      8598.2387  2802.0783   3.069 0.002469 **
## year2015      6196.6699  2802.1699   2.211 0.028215 *
## year2016      8943.6367  3350.9547   2.669 0.008273 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Approximate significance of smooth terms:
##                                      edf Ref.df      F  p-value
## s(as.numeric(eval(TIME))):year2010 0.9999  1.000 10.563 0.001362 **
## s(as.numeric(eval(TIME))):year2012 1.0000  1.000  5.035 0.025978 *
## s(as.numeric(eval(TIME))):year2013 1.0000  1.000  0.000 0.999937
## s(as.numeric(eval(TIME))):year2015 1.0000  1.000  6.445 0.011917 *
## s(as.numeric(eval(TIME))):year2016 1.0000  1.000  0.031 0.860547
## s(eval(BIRD_DENSITY)):year2010     7.4971  8.390  2.987 0.003818 **
## s(eval(BIRD_DENSITY)):year2012     1.0000  1.000  0.257 0.612484
## s(eval(BIRD_DENSITY)):year2013     1.3293  1.550  1.468 0.168807
## s(eval(BIRD_DENSITY)):year2015     3.1880  3.898  6.019 0.000165 ***
## s(eval(BIRD_DENSITY)):year2016     1.0000  1.000  0.163 0.686857
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## R-sq.(adj) =  0.728   Deviance explained = 75.8%
## GCV = 0.21414  Scale est. = 0.18899   n = 213
```

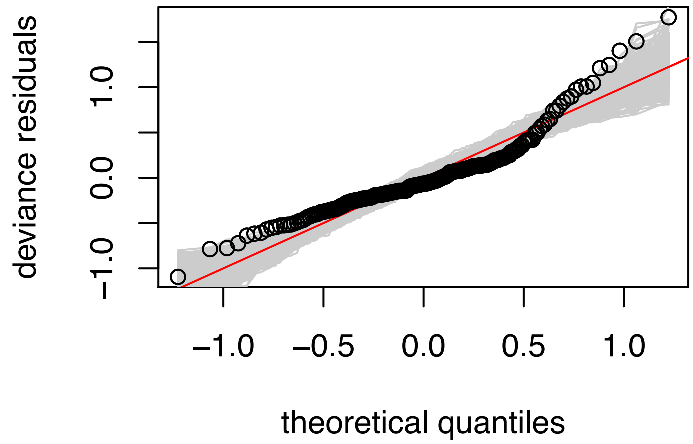
Results for the main text:

```
res = summary(bm)$p.table
res = cbind(res,Factor=10^(res[,"Estimate"]))
# Exponentiating the coefficient to get multiplicative factor
print.model.summary(res[2,5],res[2,3],res[2,4],units="x",effect.word="factor")
```

```
## [1] "factor = 1.9x, t = 3.49, P = 0.0006"
```

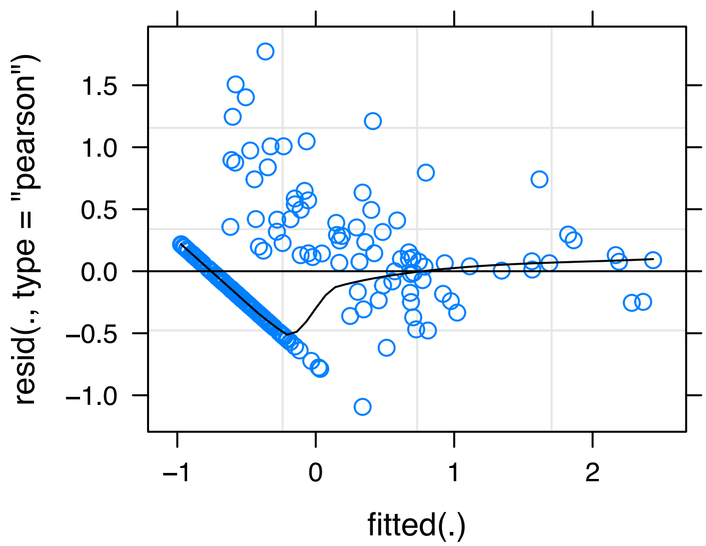
Some deviation from the normal line, but all points within the bounds of the simulated datasets, or very close.

```
qq.gam(bm,rep=1000,pch=1,level=1)
```



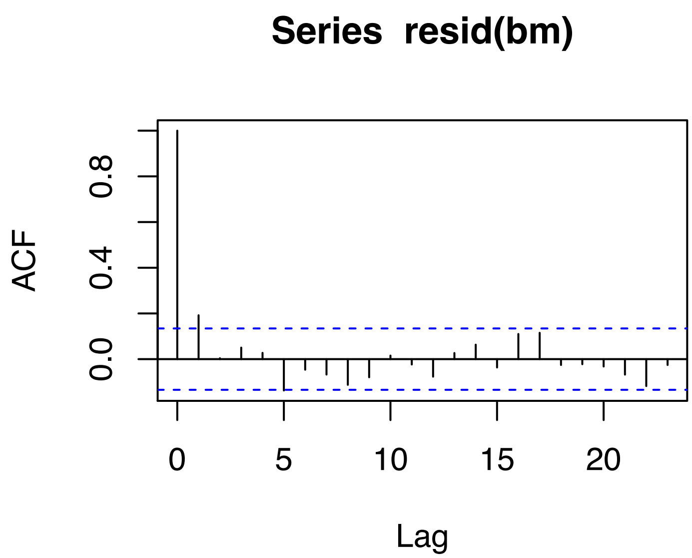
Some structure due to the large number of near-zero values in the dataset.

```r
plot.lme(bm,type=c("p","smooth"),col.line="black")
```



Negligible autocorrelation of residuals.

```r
acf(resid(bm))
```


Series resid(bm)
ACF
0.0
0.4
0.8
0
5
10
15
20
Lag

Standardized peak density

As previous section, but for standardized peak density.

0.5º elevation angle

```
peak.std.e1.model = stationary.radar.model.light("logst(peak.std.e1)",dt1,elev="e1")
```

```
##                      df      AIC
## mod.interact   25.88700 369.4469
## mod.light      19.87233 375.6902
## mod.light.year 22.19399 378.8855
```

```
bm = peak.std.e1.model
```

Best model includes $light \times year$ interaction.

```
summary(bm)
```

```
##
## Family: gaussian
## Link function: identity
##
## Formula:
## eval(parse(text = response.name)) ~ eval(LIGHT) * year + s(as.numeric(eval(TIME)),
##     by = year) + s(eval(BIRD_DENSITY), by = year)
##
## Parametric coefficients:
##                         Estimate Std. Error t value Pr(>|t|)
## (Intercept)           -1.146e+04  5.042e+03  -2.273  0.02419 *
## eval(LIGHT)1           8.075e-01  2.168e-01   3.724  0.00026 ***
## year2012               1.077e+04  5.160e+03   2.088  0.03818 *
## year2013               1.142e+04  5.166e+03   2.210  0.02836 *
## year2015               1.044e+04  5.070e+03   2.059  0.04093 *
## year2016               4.154e+03  8.692e+03   0.478  0.63329
## eval(LIGHT)1:year2012  4.105e-01  4.072e-01   1.008  0.31468
## eval(LIGHT)1:year2013 -1.998e-01  3.146e-01  -0.635  0.52623
## eval(LIGHT)1:year2015  8.522e-01  2.929e-01   2.910  0.00406 **
## eval(LIGHT)1:year2016 -1.305e-01  3.485e-01  -0.374  0.70858
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Approximate significance of smooth terms:
##                                    edf Ref.df     F p-value
## s(as.numeric(eval(TIME))):year2010 1.000  1.000 5.166  0.0242 *
## s(as.numeric(eval(TIME))):year2012 1.000  1.000 0.386  0.5351
## s(as.numeric(eval(TIME))):year2013 1.000  1.000 0.001  0.9757
## s(as.numeric(eval(TIME))):year2015 1.000  1.000 3.702  0.0559 .
## s(as.numeric(eval(TIME))):year2016 1.000  1.000 1.064  0.3035
## s(eval(BIRD_DENSITY)):year2010     4.175  5.107 2.813  0.0129 *
## s(eval(BIRD_DENSITY)):year2012     1.000  1.000 0.289  0.5917
## s(eval(BIRD_DENSITY)):year2013     1.540  1.790 2.358  0.1221
## s(eval(BIRD_DENSITY)):year2015     1.383  1.667 3.197  0.0661 .
## s(eval(BIRD_DENSITY)):year2016     1.788  2.153 1.120  0.4872
```

```
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## R-sq.(adj) =  0.453   Deviance explained = 51.6%
## GCV = 0.34495  Scale est. = 0.30388   n = 209
```

Results for main text:

```
res = summary(bm)$p.table
res = cbind(res,Factor=10^(res[,"Estimate"]))
# Exponentiating the coefficients to get multiplicative factor
print.model.summary(res[2,5],res[2,3],res[2,4],units="x",effect.word="factor")
```

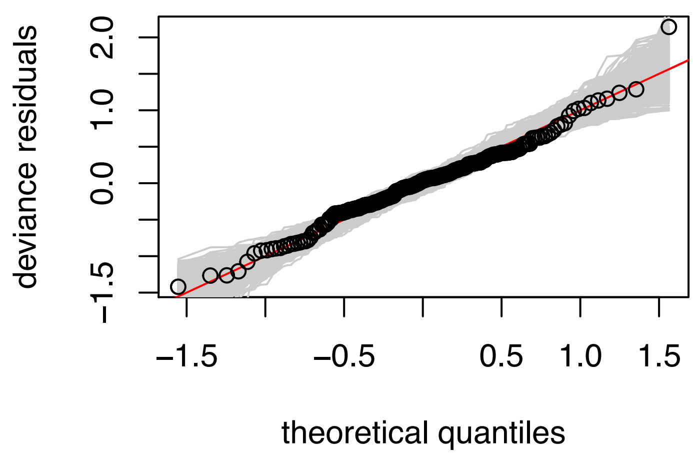
```
## [1] "factor = 6.4x, t = 3.72, P = 0.0003"
```

```
# Interaction
print.model.summary(10^(res[9,1]+res[2,1]),res[9,3],res[9,4],units="x",effect.word="factor")
```

```
## [1] "factor = 46x, t = 2.91, P = 0.0041"
```

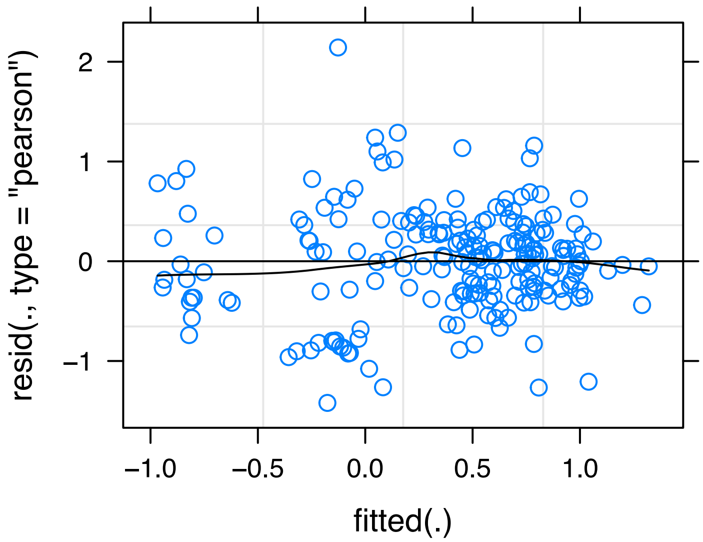
No evidence of any deviation; all points within the bounds of the simulated datasets.

```
qq.gam(bm,rep=1000,pch=1,level=1)
```



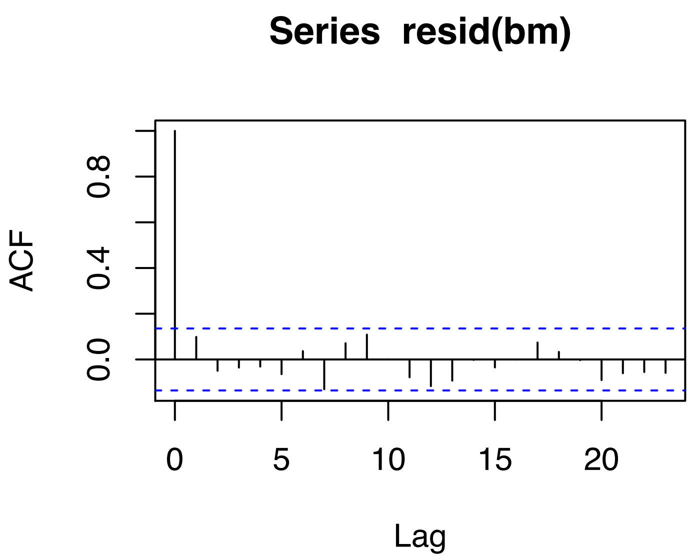
No evidence of any deviation or structure.

```
plot.lme(bm,type=c("p","smooth"),col.line="black")
```



Negligible autocorrelation of residuals.

```
acf(resid(bm))
```



1.5º elevation angle

```
peak.std.e2.model = stationary.radar.model.light("logst(peak.std.e2)",dt2,elev="e2")
```

```
##                       df      AIC
## mod.light.year 20.35718 523.5451
## mod.interact   24.43069 524.0113
## mod.light      16.56379 525.4860
```

```
bm = peak.std.e2.model
```

The best model includes *light* and *year*, but not their interaction.

```
summary(bm)
```

```
##
```

```
## Family: gaussian
## Link function: identity
##
## Formula:
## eval(parse(text = response.name)) ~ eval(LIGHT) + year + s(as.numeric(eval(TIME)),
##     by = year) + s(eval(BIRD_DENSITY), by = year)
##
## Parametric coefficients:
##                Estimate Std. Error t value Pr(>|t|)
## (Intercept)  -9104.3033  3624.2956  -2.512   0.0128 *
## eval(LIGHT)1     0.6030     0.1508   3.997 9.17e-05 ***
## year2012      3548.9179  4249.1148   0.835   0.4046
## year2013      9179.5991  4062.8409   2.259   0.0250 *
## year2015      6153.2760  3960.3706   1.554   0.1219
## year2016      7001.7664  5347.7746   1.309   0.1920
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Approximate significance of smooth terms:
##                                     edf Ref.df     F p-value
## s(as.numeric(eval(TIME))):year2010 1.000  1.000 6.287  0.0128 *
## s(as.numeric(eval(TIME))):year2012 1.000  1.000 6.248  0.0133 *
## s(as.numeric(eval(TIME))):year2013 1.000  1.000 0.000  0.9982
## s(as.numeric(eval(TIME))):year2015 1.000  1.000 3.408  0.0664 .
## s(as.numeric(eval(TIME))):year2016 1.000  1.000 0.286  0.5932
## s(eval(BIRD_DENSITY)):year2010     1.873  2.358 1.040  0.3603
## s(eval(BIRD_DENSITY)):year2012     1.000  1.000 1.462  0.2281
## s(eval(BIRD_DENSITY)):year2013     1.790  1.956 0.313  0.6989
## s(eval(BIRD_DENSITY)):year2015     2.573  3.188 2.310  0.0881 .
## s(eval(BIRD_DENSITY)):year2016     1.122  1.231 0.080  0.7182
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## R-sq.(adj) =  0.291   Deviance explained = 35.4%
## GCV = 0.71656  Scale est. = 0.65019   n = 209
```

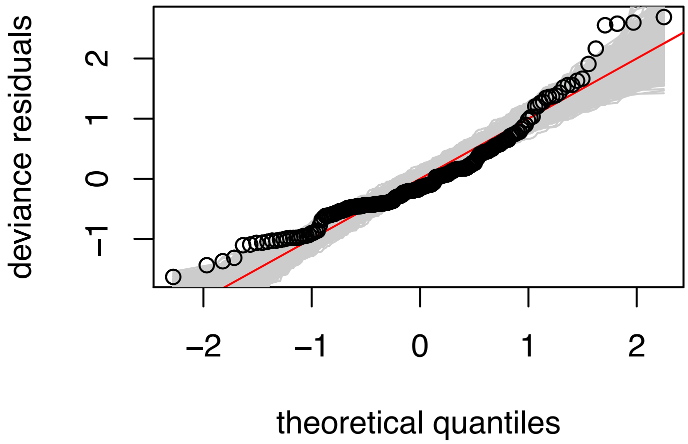
Results for the main text:

```
res = summary(bm)$p.table
res = cbind(res,Factor=10^(res[,"Estimate"]))
# Effect of light after exponentiating the coefficient to get multiplicative factor
print.model.summary(res[2,5],res[2,3],res[2,4],units="x",effect.word="factor")
```

```
## [1] "factor = 4x, t = 4.00, P < 0.0001"
```

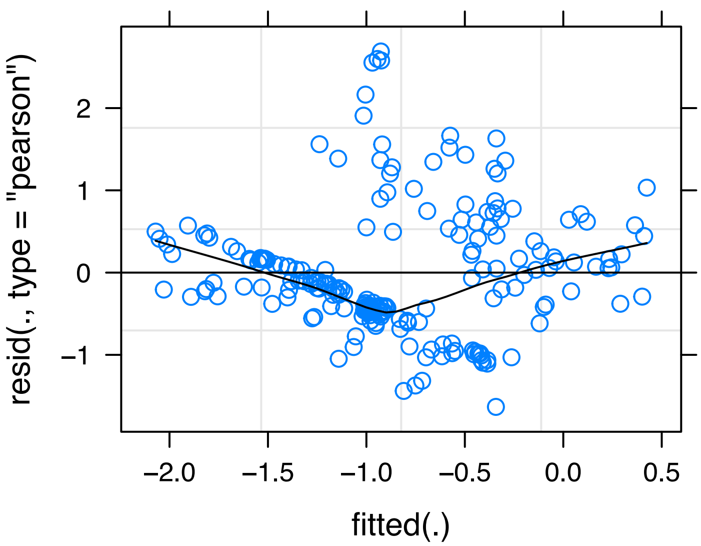
Some deviation from the normal line, but all points are either within the bounds of the simulated datasets or very close.

```
qq.gam(bm,rep=1000,pch=1,level=1)
```



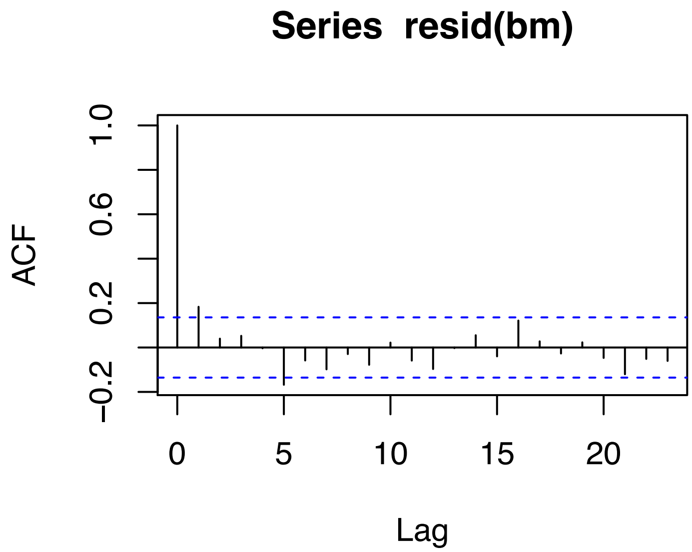
Appears to be some structure (likely due to large numbers of near-zero values), but not dramatic.

```
plot.lme(bm,type=c("p","smooth"),col.line="black")
```



Negligible autocorrelation of residuals.

```
acf(resid(bm))
```



Series resid(bm)
ACF
1.0
0.6
0.2
−0.2
0
5
10
15
20
Lag

Radial velocity

Note that radial velocity data have *not* been log-transformed.

0.5º elevation angle

```
velocity.e1.model = stationary.radar.model.light("velocity.cyl.e1",dt1,elev="e1")
```

```
##                      df      AIC
## mod.interact   29.28329 814.1776
## mod.light.year 25.70874 817.0279
## mod.light      23.24699 819.2017
```

```
bm = velocity.e1.model
```

The best model includes the *light* × *year* interaction term.

```
summary(bm)
```

```
##
## Family: gaussian
## Link function: identity
##
## Formula:
## eval(parse(text = response.name)) ~ eval(LIGHT) * year + s(as.numeric(eval(TIME)),
##     by = year) + s(eval(BIRD_DENSITY), by = year)
##
## Parametric coefficients:
##                         Estimate Std. Error t value Pr(>|t|)
## (Intercept)            5.221e+04  2.260e+04   2.310   0.0221 *
## eval(LIGHT)1          -1.670e+00  7.951e-01  -2.101   0.0372 *
## year2012              -5.063e+04  2.314e+04  -2.188   0.0301 *
## year2013              -5.197e+04  2.286e+04  -2.274   0.0243 *
## year2015              -4.947e+04  2.287e+04  -2.163   0.0320 *
## year2016              -9.960e+03  3.079e+04  -0.323   0.7468
## eval(LIGHT)1:year2012 -3.714e+00  1.558e+00  -2.384   0.0183 *
## eval(LIGHT)1:year2013 -1.773e+00  1.496e+00  -1.185   0.2376
## eval(LIGHT)1:year2015 -2.678e+00  1.062e+00  -2.521   0.0127 *
## eval(LIGHT)1:year2016 -5.909e-01  1.223e+00  -0.483   0.6296
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Approximate significance of smooth terms:
##                                    edf Ref.df     F p-value
## s(as.numeric(eval(TIME))):year2010 1.000  1.000 5.337 0.02212 *
## s(as.numeric(eval(TIME))):year2012 1.000  1.000 0.012 0.91154
## s(as.numeric(eval(TIME))):year2013 1.000  1.000 0.013 0.91010
## s(as.numeric(eval(TIME))):year2015 1.000  1.000 0.600 0.44006
## s(as.numeric(eval(TIME))):year2016 1.000  1.000 4.078 0.04511 *
## s(eval(BIRD_DENSITY)):year2010     3.358  4.210 4.221 0.00181 **
## s(eval(BIRD_DENSITY)):year2012     2.853  2.986 3.346 0.02230 *
## s(eval(BIRD_DENSITY)):year2013     1.769  1.951 0.475 0.64828
## s(eval(BIRD_DENSITY)):year2015     4.303  5.233 3.661 0.00322 **
## s(eval(BIRD_DENSITY)):year2016     1.000  1.000 0.493 0.48343
```

```
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## R-sq.(adj) =  0.601   Deviance explained = 65.9%
## GCV = 4.4118  Scale est. = 3.7515    n = 189
```

Results for main text:

```
res = summary(bm)$p.table
print.model.summary(res[2,1],res[2,3],res[2,4],units="m/s",effect.word="effect")
```

```
## [1] "effect = -1.7 m/s, t = -2.10, P = 0.0372"
```

```
# Interaction - 2012
print.model.summary(res[7,1]+res[2,1],res[7,3],res[7,4],units="m/s",
                    effect.word="effect with interaction")
```

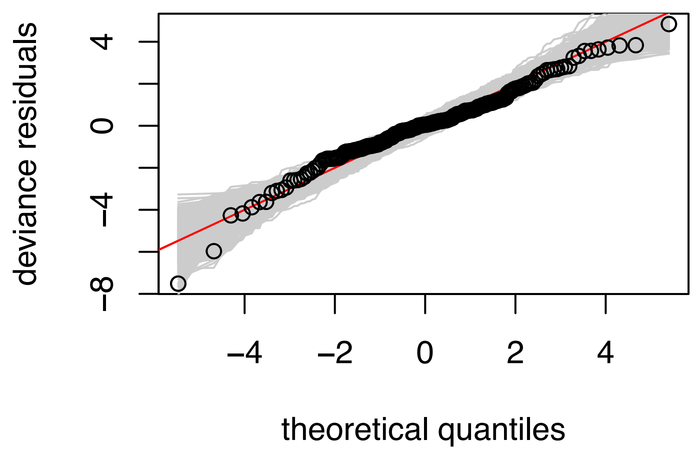
```
## [1] "effect with interaction = -5.4 m/s, t = -2.38, P = 0.0183"
```

```
# Interaction - 2015
print.model.summary(res[9,1]+res[2,1],res[9,3],res[9,4],units="m/s",
                    effect.word="effect with interaction")
```

```
## [1] "effect with interaction = -4.3 m/s, t = -2.52, P = 0.0127"
```

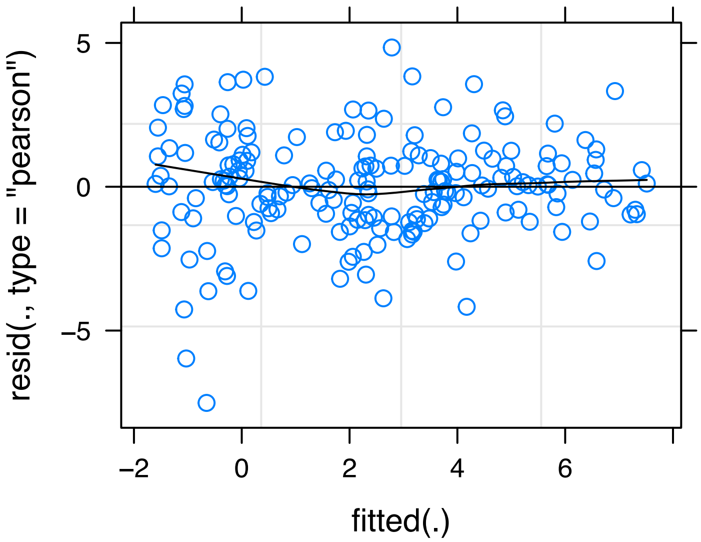
No strong evidence of any deviation; all points within the bounds of the simulated datasets.

```
qq.gam(bm,rep=1000,pch=1,level=1)
```



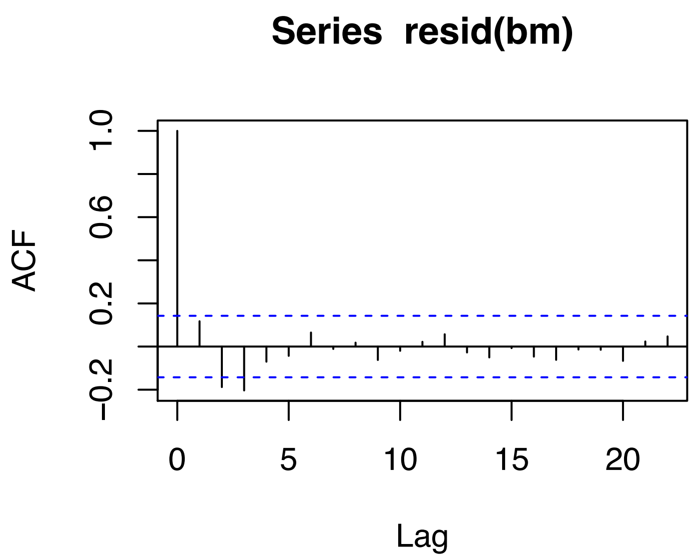
No evidence of any deviation or structure.

```
plot.lme(bm,type=c("p","smooth"),col.line="black")
```



Negligible autocorrelation of residuals.

```r
acf(resid(bm))
```



Number of flight calls

```r
response.name="logst(n.calls)"
elev="e1"
```

```r
aic = AIC(mod.interact,
          mod.light.year,
          mod.light); aic
```

```
##                       df       AIC
## mod.interact   26.22691 -364.0446
## mod.light.year 22.57075 -276.7783
## mod.light      22.52872 -276.8101
```

```r
calls.e1.model = eval(parse(text=rownames(aic)[which.min(aic$AIC)]))
bm = calls.e1.model
```

The best model includes the $light \times year$ interaction term.

```r
summary(bm)
```

```
##
## Family: gaussian
## Link function: identity
##
## Formula:
## eval(parse(text = response.name)) ~ eval(LIGHT) * year + max_eta.e1 +
##     s(as.numeric(eval(TIME)), by = year) + s(eval(BIRD_DENSITY),
##     by = year)
##
## Parametric coefficients:
##                          Estimate Std. Error t value Pr(>|t|)
## (Intercept)            -2.342e+01  2.880e+00  -8.134 1.38e-13 ***
## eval(LIGHT)1            1.519e-01  3.356e-02   4.527 1.20e-05 ***
## year2013                7.632e+00  3.756e+00   2.032  0.04390 *
## year2015               -5.346e+01  5.492e+00  -9.733  < 2e-16 ***
## year2016                9.635e+00  3.070e+00   3.138  0.00204 **
## max_eta.e1              4.233e-07  1.427e-06   0.297  0.76706
## eval(LIGHT)1:year2013 -1.087e-01  4.737e-02  -2.296  0.02306 *
## eval(LIGHT)1:year2015  3.107e-01  4.517e-02   6.877 1.49e-10 ***
## eval(LIGHT)1:year2016 -9.658e-02  5.088e-02  -1.898  0.05957 .
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Approximate significance of smooth terms:
##                                    edf Ref.df      F  p-value
## s(as.numeric(eval(TIME))):year2010 0.8308 0.8309 99.157  < 2e-16 ***
## s(as.numeric(eval(TIME))):year2013 1.0912 1.2291 35.199 0.001458 **
## s(as.numeric(eval(TIME))):year2015 1.5598 1.5603 69.656  < 2e-16 ***
## s(as.numeric(eval(TIME))):year2016 0.5385 0.5388 23.884 0.000447 ***
## s(eval(BIRD_DENSITY)):year2010     6.2036 7.0849  7.762 2.59e-08 ***
## s(eval(BIRD_DENSITY)):year2013     1.0000 1.0000  0.638 0.425828
## s(eval(BIRD_DENSITY)):year2015     6.0761 7.0266 17.366  < 2e-16 ***
## s(eval(BIRD_DENSITY)):year2016     1.1145 1.2185  0.129 0.629785
## ---
```

```
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Rank: 65/81
## R-sq.(adj) =  0.949   Deviance explained = 95.6%
## GCV = 0.0075709  Scale est. = 0.0064918  n = 177
```

Results for the main text:

```
res = summary(bm)$p.table
res = cbind(res,Factor=10^(res[,"Estimate"]))
# Effect of light after exponentiating the coefficient to get multiplicative factor
print.model.summary(res[2,5],res[2,3],res[2,4],units="x",effect.word="factor")
```

```
## [1] "factor = 1.4x, t = 4.53, P < 0.0001"
```

```
# Interaction - 2013
print.model.summary(10^(res[7,1]+res[2,1]),res[7,3],res[7,4],units="x",
                    effect.word="factor with interaction")
```

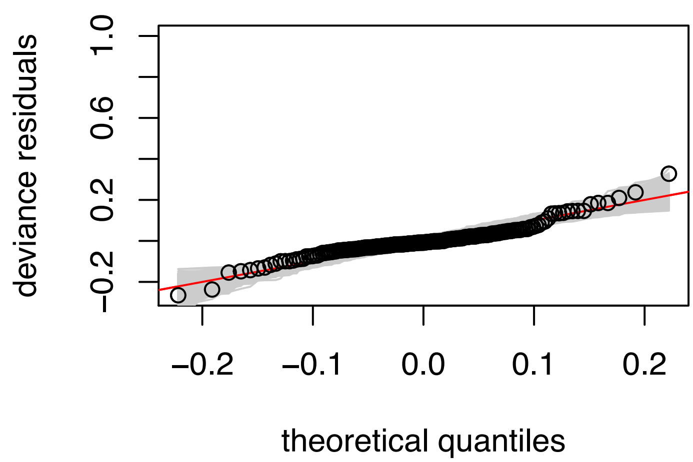
```
## [1] "factor with interaction = 1.1x, t = -2.30, P = 0.0231"
```

```
# Interaction - 2015
print.model.summary(10^(res[8,1]+res[2,1]),res[8,3],res[8,4],units="x",
                    effect.word="factor with interaction")
```

```
## [1] "factor with interaction = 2.9x, t = 6.88, P < 0.0001"
```

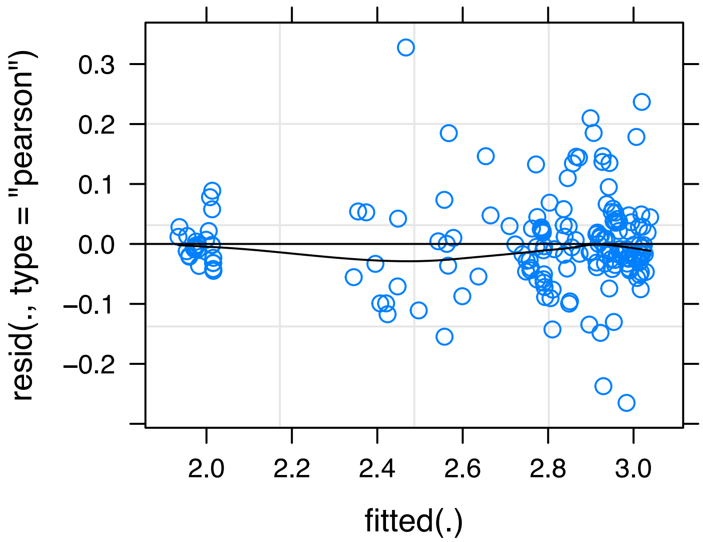
No strong evidence of any deviation; all points within the bounds of the simulated datasets.

```
qq.gam(bm,rep=1000,pch=1,level=1)
```



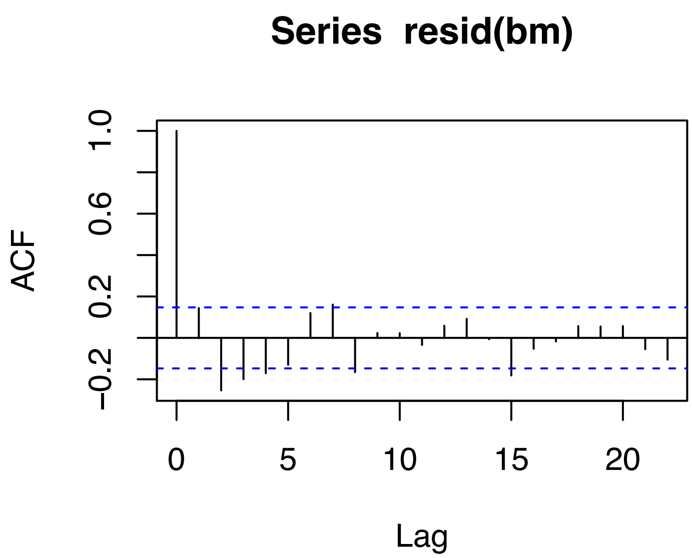
Although the variance increases, this does not affect the regression coefficients; it may make the test more conservative (i.e. more difficult to detect a statistical difference between illuminated and dark periods or between years).

```
plot.lme(bm,type=c("p","smooth"),col.line="black")
```



Negligible autocorrelation of residuals.

```
acf(resid(bm))
```



Number of birds affected by the lights

Here we estimate the total number of birds affected by the lights. Our best estimate of turnover time comes from the simulations, where the stabilization time is 34 minutes. Since on average there should be complete turnover within that period of time, we use 34 minutes as our best estimate of the turnover time. Then we find the median time between radar scans in minutes

```
time.between.scans = as.numeric(median(diff(data.m$sweep.time.e1))); time.between.scans
```

```
## [1] 9.466667
```

Next we divide the time between scans by the turnover time to find the proportion of samples that can be treated as 'independent.' We will therefore calculate total numbers of birds only from a subset of the dataset of this size.

```
retain.proportion = time.between.scans/34; retain.proportion
```

```
## [1] 0.2784314
```

To accomplish this, we subsample the dataset 10000 times with the probablity of keeping a data point equal to 'retain.proportion.'

```
set.seed(123)
yrs = sort(unique(data.m$year))
n.sim = 1e4
res.array = array(dim=c(n.sim,length(yrs)))
# xx = rep(NA,n.sim)
for (i in 1:n.sim) {
res.array[i,] = with(data.m[sample.int(nrow(data.m),size=nrow(data.m)*retain.proportion),],
             tapply(n.birds.difference.5k.e1,year,sum,na.rm=T)) # %>% sum
}
colnames(res.array) = levels(data.m$year)
```

We take the mean value of these 10000 iterations as our best estimate of number of the total number of birds affected by the lights during the study period, rounded to nearest hundred thousand.

```
# All years combined
apply(res.array,2,mean) %>% sum %>% round(-5)
```

```
## [1] 1100000
```

```
# Breakdown by year
apply(res.array,2,mean) %>% round(-3)
```

```
##   2008   2010   2012   2013   2014   2015   2016
##  21000 669000  29000 198000   5000 130000  34000
```

```
# Mean year
apply(res.array,2,mean) %>% mean %>% round(-4)
```

```
## [1] 160000
```

```
# Standard deviation
apply(res.array,2,mean) %>% sd %>% round(-4)
```

```
## [1] 240000
```

```
# Median year
apply(res.array,2,mean) %>% median %>% round(-4)
```

```
## [1] 30000
```

Finally, we calculate a 95% confidence interval for this estimate by finding the 0.025 and 0.975 quantiles of the 10000 iterations.

```
# All years combined
round(quantile(apply(res.array,1,sum),probs=c(.025,.975)),-5)
```

```
##    2.5%   97.5%
##  600000 1600000
```

```
# By year
apply(res.array,2,quantile,probs=c(.025,.975)) %>% round(-3)
```

```
##        2008    2010  2012   2013  2014   2015  2016
## 2.5%   9000  217000 13000 110000     0  47000 15000
## 97.5% 34000 1178000 47000 298000 12000 229000 55000
```