Unifying Communities: with an open data research project
to determine the time of fajr in Birmingham, UK

Abstract

Objective

Although there is consensus on the textual definition of fajr across Muslim denominations, there is wide variation in the implementation of the time of fajr across different communities. Our project aims to enable the harmonisation and unification of the time at which the fajr prayer is conducted (and the commencement of the fast), by providing accurate data, using specialist technology.

Introduction

Some communities approximate the time of fajr using different calculation methods; however, there is no consensus on a specific formula. Some communities base their timetables on local observations; however, these may be subject to observer bias and may not be reproducible. This results in a wide variation amongst different fajr timetables. We suggest that formulating a fajr timetable by either individual's observations alone, or calculations alone, will not achieve a unified prayer timetable.

Method

A specialist "all-night camera", designed for astrophysics research (with a 180° fish-eye lens with CCD detector capable of discerning low ambient light variance at the horizon), was mounted at a site within Birmingham. The camera was programmed to take photographs every minute of the sky, and all photographs spanning a calendar year have been published on the project website.

Analysis

A consensus panel was assembled, comprising of religious scholars, academics and researchers in this field, experienced observers, community leaders, and umbrella organisations. Members of the consensus panel individually assessed the images, and voted for the image they perceived to correspond most closely with the time of fajr. The results were analysed to produce an annual timetable.

Results

The OpenFajr research project has produced the largest body of published observational data in our latitude. The proposed annual fajr timetable is presented in this paper, and we propose the dissemination of this research paper to organisations and individuals for their critique, for them to consider the adoption of the proposed timetable.

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Introduction

The time of [true] fajr is defined in the Qurʾān as when the "whiteness of the day becomes distinct from the blackness of the night at dawn" [1]; and this definition is further clarified in ḥadīth literature as when the light "spreads horizontally" [2] and not when the light "looks

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[1] Chapter Al-Baqarah (2), Verse 187
... وكلوا واشربوا حتى يتبين لكم الخيط الابيض من الخيط الاسود من الفجر...

[2] Al-Bukhari: Volume 1, Book 11, Number 595
'Abdullah bin Mas'ud narrated: The Prophet said, "The Adhan pronounced by Bilal should not stop you from taking Suhur, for he pronounces the Adhan at night, so that the one offering the late night prayer (Tahajjud) from among you might hurry up and the sleeping from among you might wake up. It does not mean that dawn or morning has started." Then He (the Prophet) pointed with his fingers and raised them up (towards the sky) and then lowered them (towards the earth) like this (Ibn Mas'ud imitated the gesture of the Prophet). Az-Zuhri gestured with his two index fingers which he put on each other and then stretched them to the right and left. These gestures illustrate the way real dawn appears. It spreads left and right horizontally. The dawn that appears in the high sky and lowers down is not the real dawn.

like the tail of a wolf" [3] or is "vertical" [4] [which is the false fajr]. The juristic definition of fajr is "the appearance of a clear and distinct line of light along the eastern horizon" [5], described also "when this whiteness spreads" [6].

In scientific terms, false dawn is defined at the point when a vertical column of light is visible on the eastern horizon (note that this [zodiacal light] is only visible in the latitude of Birmingham prior to sunrise in the autumn); true dawn is when there is the first horizontal spread of light on the eastern horizon (which supersedes the vertical column of light [if present]). This is the time of fajr.

Across the Muslim community, there is consensus on the definition of the time of fajr; however, there is wide variance in its application, resulting in differing timetables.

Timetables that different communities may adopt based on their own observations differ in view of "observer bias": observers have different experience and expertise in discerning fajr; their visual acuities and ability to discern low-light intensities may differ; they may interpret the images differently; they may have spent varying times allowing their eyes to acclimatise to the low light intensities; and they may be influenced by "memory bias", as it is not possible to replay the memory of images in the mind to discern if fajr may have occurred just prior. Similarly, with timetables based on individual's observations, the data is not reproducible, not open to critique, and a large number of data points will be needed to establish a robust prayer timetable with high statistical confidence.

Similarly, developing a timetable for fajr based on calculations has limitations too, as there is no consensus (either in religious scholarly or scientific circles) on the formula to apply. Some communities apply a fixed solar angle of depression prior to sunrise; some approximate the time of fajr using a fixed-time before sunrise; others by apportioning the night (typically into seven, with fajr one-seventh the night prior to sunrise); others by apportioning the length of day (similarly to above); and some a hybrid of these, which is typically adopted in areas of higher latitude (in northern or southern countries), where the sun often does not decline beneath the typical angles. Without consensus on any of these methods, widespread uptake of such a timetable across all communities would be very difficult.

In our literature review, the majority of Islamic organisations in Birmingham publish the time of fajr based on a fixed-time of 1 hour and 40 minutes (or similar) prior to sunrise. Discussing the history of this with Birmingham Central Mosque, we were informed that individual observers noticed a variance in the time-lag between fajr and sunrise across the seasons in Birmingham; the average of these time-lags was then applied across the whole year, which came into effect in 1991.

In our literature review, we note that there is a body of observational evidence in certain countries to support the correlation of observational data with a specific formula for the time of fajr: some countries adopt a fixed solar depression angle, others a fixed-time prior to sunrise[7]. However, there is a paucity of published observational data in higher latitudes. If one were to simply transpose the formula from an equatorial or lower latitude area to a higher latitude area, it would be assumptive and this approach does not consider publication bias:

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[3] Al-Jaami': Hadith Number 4278
Jabir ibn Abdullah (RA) narrated: The Messenger (SAW) said there are two fajrs. The fajr which looks like the tail of a wolf: at such a time fajr prayer is not allowed, but the food intake is not forbidden either. The [next] fajr that spreads horizontally in the sky marks the time when fajr prayer is permitted and food is forbidden.

[4] Wasaa'il: Hadith Number 4944
In a letter from Imam Al-Jawad (Abu Ja'far Al-Thaani): Fajr is the horizontal 'white thread' and it isn't the vertical whiteness, so don't pray in travel or otherwise until you verify it, for Allah hasn't left his creation in uncertainty in this affair and He has said: "Eat and drink until the white thread becomes clear from the black thread of morning". The white thread is the horizontal [one] and it is the one in which salaat becomes wajib.

[5] The Permanent Committee for Scholarly Research and Ifta': Fatwa No. 7373: Part No. 6; Page No. 144.
http://alifta.com/fatawa/fatwaprint.aspx?languagename=en&id=1905&bookid=&sectionid=7. Accessed online 26/10/2015
Astronomical calculations are not consequential in determining the times of Salah (prayer), but what is crucial when determining the time for the Fajr Prayer is to take into account the appearance of a clear and distinct line of light along the eastern horizon. The time ends when the sun rises.

[6] Ayatullah Sayyid Abulqasim al-Khui: Laws of Prayers: Rule No. 749.
http://www.al-islam.org/islamic-laws-ayatullah-abul-qasim-al-khui/prayers#time-dawn-prayers. Accessed online 26/10/2015
Near about the call for dawn prayers a whiteness rises from the east, it is called the first dawn (Fajr). When this whiteness spreads, it is called the second dawn, this the time for dawn prayers commences [sic]. This time ends with sunrise.

[7] Dr Khalid Shaukat (2012): Fajr and Isha. Available via http://www.moonsighting.com/how-we.html. URL accessed online 25/04/2016

Considering the factors that create the visual phenomenon of the first horizontal spread of light on the horizon prior to sunrise, with the light refracting and scattering in our atmosphere: we prefer not to assume that the only factor that determines the time of fajr is the two-dimensional solar depression angle; and we note the significant variation in the three-dimensional trajectory of the path of the sun as it rises. For example, at the equator, it takes only 24 minutes for the sun to rise from -18 to -12 degrees. But in our latitude in the summer, it is many weeks before the sun declines that far down again. And further north, this period is many months. So the trajectory of the sun as it rises up is different in every latitude. But it is also different every day. The images below illustrate this[8].

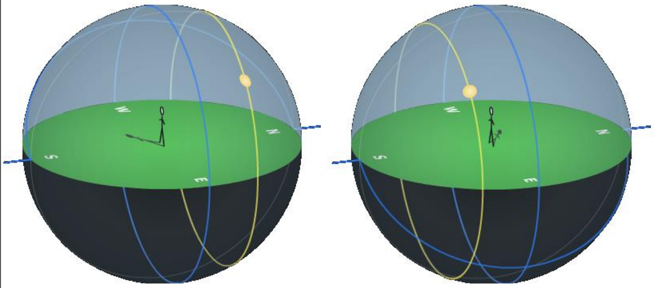


FIGURE 1 (ABOVE):
PATH OF THE SUN AT THE EQUATOR AT THE SUMMER SOLSTICE (LEFT) AND THE WINTER SOLSTICE (RIGHT)

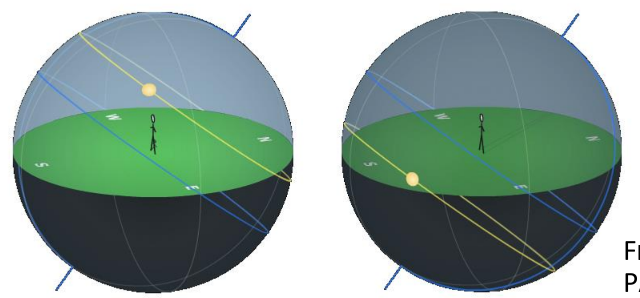


FIGURE 2 (LEFT):
PATH OF THE SUN AT THE LATITUDE OF BIRMINGHAM AT THE SUMMER SOLSTICE (LEFT) AND THE WINTER SOLSTICE (RIGHT)

There is a lack of evidence to support the theory that a specific formula models the time of fajr accurately across all latitudes and across all seasons. Therefore, we are cautious about making the assumption, that if the observed time of fajr is at a particular solar depression angle (or time-lag before sunrise) in a location, then it will necessarily be that angle (or time-lag) in another location. Additionally, we are cautious about the assumption that this solar depression angle (or time-lag) will be the same in that location in another season, or even the next day. We note the lack of published statistical analysis to verify the accuracy of fajr timetables in Birmingham, regardless of how they were formulated.

We also note other factors that could influence the path of the sun's light through the atmosphere at different latitudes, such as the differential scattering and refraction of light through the different layers of our atmosphere, as the layers of the Earth's atmosphere vary with latitude[9].

In view of these issues, and the juristic opinion that "astronomical calculations are not consequential in determining the times of ṣalāh (prayer), but what is crucial when determining the time for the fajr prayer is to take into account the appearance of a clear and distinct line of light along the eastern horizon" [5], our project aims to harmonise and unify the time at which the fajr prayer is conducted (and the commencement of the fast) by providing accurate and robust observational data, that is open, transparent, verifiable, expert-reviewed, and reproducible.

Methodology

Rather than adopting an "authoritarian" or "guardianship" model, we preferred to raise awareness, educate, empower and engage with individuals and communities. Therefore, we have chosen to adopt an "open data" model for this research project. In developing our methodology, we consulted with religious scholars, scientists (including Her Majesty's Nautical Almanac Office [HMNAO]), and experts in the fields of IT, photography, and material engineering.

We acquired photographs of the sky, taken at one-minute intervals, spanning the variance of the different timetables published by mosques in Birmingham (and in addition to this to

[8] Images captured from "Motions of the Sun Simulator", produced by the Astronomy department of the University of Nebraska-Lincoln, http://astro.unl.edu/classaction/animations/coordsmotion/sunmotions.html. Accessed online 26/06/2015
[9] B Geerts, E Linacre (1997): The height of the tropopause. University of Wyoming. http://www-das.uwyo.edu/~geerts/cwx/notes/chap01/tropo.html. Accessed online 28/04/2016

include approximately 90 minutes of photographs per morning). This methodology achieves the goal of acquiring transparent, verifiable and reproducible data. We critiqued various cameras and discussed their suitability for our research with the manufacturers. We chose to acquire a CCD all-sky camera, designed for astrophysics research, the specifications of which are listed below[10].

The camera was mounted at a site in Birmingham[11], in a residential district approximately 4 miles south from the city centre, so that the view of fajr to the east was not overlooking the city centre. The camera was set up in September 2014 and was tested: this included the appraisal of photographs with different exposure lengths to confirm congruency with actual observations, and the exposure length of each photograph was then set at 10 seconds. We started publishing photographs from December 2014 on the website.

The camera was benchmarked against actual [controlled human] observations by the research team, at the location of the camera, and additionally at 4 other sites at the southern and eastern borders of the city, and across the seasons, to confirm that the photographs were congruent with actual observations.

From June 2015, when we had published over 6 months' data, we engaged further with scientific and research organisations, mosques and individuals. Critiquing the images was encouraged, and suggested timings based on the photographs were published on the website to promote discussion.

In December 2015, we completed one calendar year of data gathering. The databases were locked, and the suggested times on the website were removed (in order to prevent bias in the data validation process). A data validation module was created, accessible online, for participants to complete individually and impartially to mitigate against "response bias", and also to allow experts in the field who are not based locally to participate. The data validation process started with a video explaining the project and the methodology. The participants then watched a tutorial video which discussed the interpretation of the images and identification of fajr, including advice on viewing the photographs on a large high-resolution display and keeping the viewing experience constant. During the tutorial video, two sets of control images were shown in a slideshow, for when the observation benchmarking process had taken place, to highlight to participants how to discern fajr on the photographs. Following this, participants commenced the data validation module, which comprised of 42 series of images, and for each series of images participants were asked to vote on the photographs when they discerned fajr (or if they were unable to). All photographs were uncompressed, had their time-stamps removed and replaced with a letter (to mitigate against bias), and an arrow placed on the first photograph of each set of images to indicate to the participant the direction of the first spread of light on that morning. The photographs were assembled in a slideshow, to allow the participant to move backwards and forwards through the images as desired.

To establish the consensus panel of participants to validate the data, we invited religious scholars, academics and researchers in this field, experienced observers, community leaders, and umbrella organisations to take part; approximately 60 such invitations were sent. We also encouraged invitees to share the details of the project with their networks, and to contact us to suggest additional participants who we then invited to join the consensus panel. Additionally, we wrote to all 170 mosques and Muslim organisations in Birmingham which were listed in an online directory, with a postal invitation to join the consensus panel if in their community there were individuals with interest, experience or expertise in the field. All invitations included a unique PIN code that had to be entered on the first page of the data validation module to confirm the participant's identity. The dates for the data validation module to be completed were set between 08/12/2015 and 08/01/2016.

[10] CCD type: ICX205AL Sony SuperHAD interline CCD with low dark current and vertical anti-blooming. CCD Full resolution pixel data: Pixel size: 4.65µM x 4.65µM, Image format: 1392 x 1040 pixels. CCD Image area: 6.4mm (Horizontal) x 4.75mm (Vertical). Spectral Response: QE max at 520nM (~50%), 30% at 420nM and 670nM. Readout Noise: Less than 10 electrons RMS - typically only 7 electrons. Full-well capacity: Greater than 15,000 e- (unbinned). Anti-blooming: Overload margin greater than 1000x. Dark current: Less than 0.1 electrons/second @ + 10C ambient. Data format: 16 bits. System gain: 0.3 electrons per ADU. Lens details: 1.55mm FL F/2 180 degree 'Fish Eye'

[11] latitude 52.44; longitude -1.95

Results & Statistical Analysis

We obtained data from 300 days (each with approximately 90 minutes of sequential photographs); we were unable to obtain data for every day, as the building on which the camera was mounted was undergoing some renovations, resulting in some power failures. 42 sets of images were from days deemed as having a clear view to the eastern horizon (which were presented to the consensus panel), and 33 sets of images from days with a partial view. There was an adequate spread of these images across the seasons. All of the photographs are available to view on the project website[12], arranged by month and day, with each day labelled to indicate if the view was clear, partial or obstructed.

The consensus panel comprised of 19 individuals, representing the following organisations (alphabetically): Birmingham Central Mosque; Council of European Jamaats [Hilal Advisory Team]; Her Majesty's Nautical Almanac Office [HMNAO]; Islamic Crescents Observation Project [ICOP]; Seminary of Najaf; The Muath Trust [Amanah Masjid]; United Kingdom Islamic Mission [UKIM]; University of Cambridge [Institute of Astronomy]. Of the panel members, 2 individuals were dual-trained as both religious scholars and scientists (one a Mufti, one with a degree in astrophysics); 14 who self-identified as experienced observers; 2 with doctorates in physics/astrophysics; 6 with other degrees in physics/astrophysics; 1 with an engineering doctorate; 6 with other scientific master's degrees or doctorates; 1 IT consultant with photography expertise; and 4 individuals responsible for developing prayer timetables for their respective mosques.

In order to summarise the results of the consensus panel, the modal value (the image with the most number of votes) was used to determine the time of fajr. The main reason for using the mode, and not another measure of central tendency (i.e. the mean or the median), was that we were interested in the overall consensus of the panel as opposed to the middle of the distribution of opinions. Sensitivity analyses using the mean and median of the consensus panel's choices showed only very slight differences between the results when using the mode compared with either of the latter two measures. Where multimodal (when there was more than one image with the

Date	Consensus Panel Fajr Time (GMT)	Corresponding solar depression angle (degrees)
11-Jan	6:44	13.0
19-Jan	6:38	13.1
24-Jan	6:35	12.9
6-Feb	6:13	13.7
18-Feb	5:53	13.6
22-Feb	5:45	13.7
23-Feb	5:46	13.2
24-Feb	5:46	12.9
27-Feb	5:39	13.0
20-Apr	3:11	15.0
22-Apr	3:09	14.5
27-Apr	3:02	13.7
28-Apr	3:00	13.6
13-May	2:24	13.0
17-May	2:16	12.8
20-May	2:04	13.1
23-May	1:58	13.0
27-May	1:47	13.0
4-Jun	1:32	12.9
6-Jun	1:31	12.7
7-Jun	1:32	12.6
8-Jun	1:27	12.7
9-Jun	1:26	12.7
10-Jun	1:26	12.6
22-Jun	1:22	12.5
30-Jun	1:32	12.3
6-Jul	1:29	13.0
10-Jul	1:37	13.0
18-Jul	1:46	13.8
21-Jul	1:56	13.7
16-Aug	3:02	14.3
28-Aug	3:32	14.2
6-Sep	3:46	14.9
7-Sep	3:51	14.5
23-Sep	4:22	14.6
26-Sep	4:29	14.4
27-Sep	4:32	14.3
13-Nov	5:56	13.5
28-Nov	6:18	13.4
10-Dec	6:35	12.9
19-Dec	6:41	13.1
25-Dec	6:47	12.6

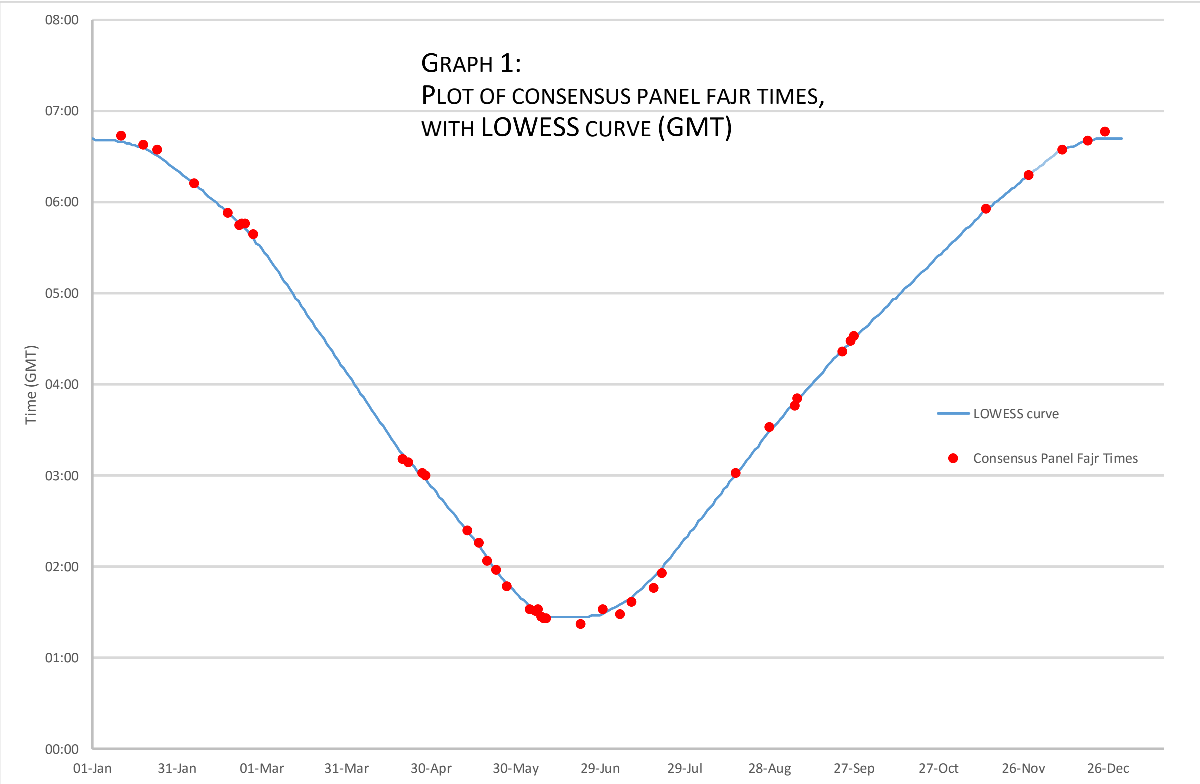
TABLE 1:
CONSENSUS PANEL TIMES OF FAJR; WITH CORRESPONDING SOLAR DEPRESSION ANGLE

[12] http://www.openfajr.org/#data

most number of votes), the higher modal value was taken, so as to never underestimate the time of fajr (so people would not perform the fajr prayer too early). These data points are presented in Table 1.

The analysis of the data was performed using STATA 13 software by an external professional statistician.

As our project is primarily an observation research study, we chose not to make an assumption of a formula which determines the time of fajr, by which to base a standard regression analysis upon. Rather, we chose to use the LOWESS (locally weighted scatterplot smoothing) analysis, which is a validated non-parametric regression method, to create an annual timetable from the consensus panel data points. For the dates between the last data point (28th November) and the first data point (10th December), the equation [change in observed fajr / change in days] was used to bridge the gap of the LOWESS curve. Graph 1 below demonstrates these curves, and the consensus panel fajr times:

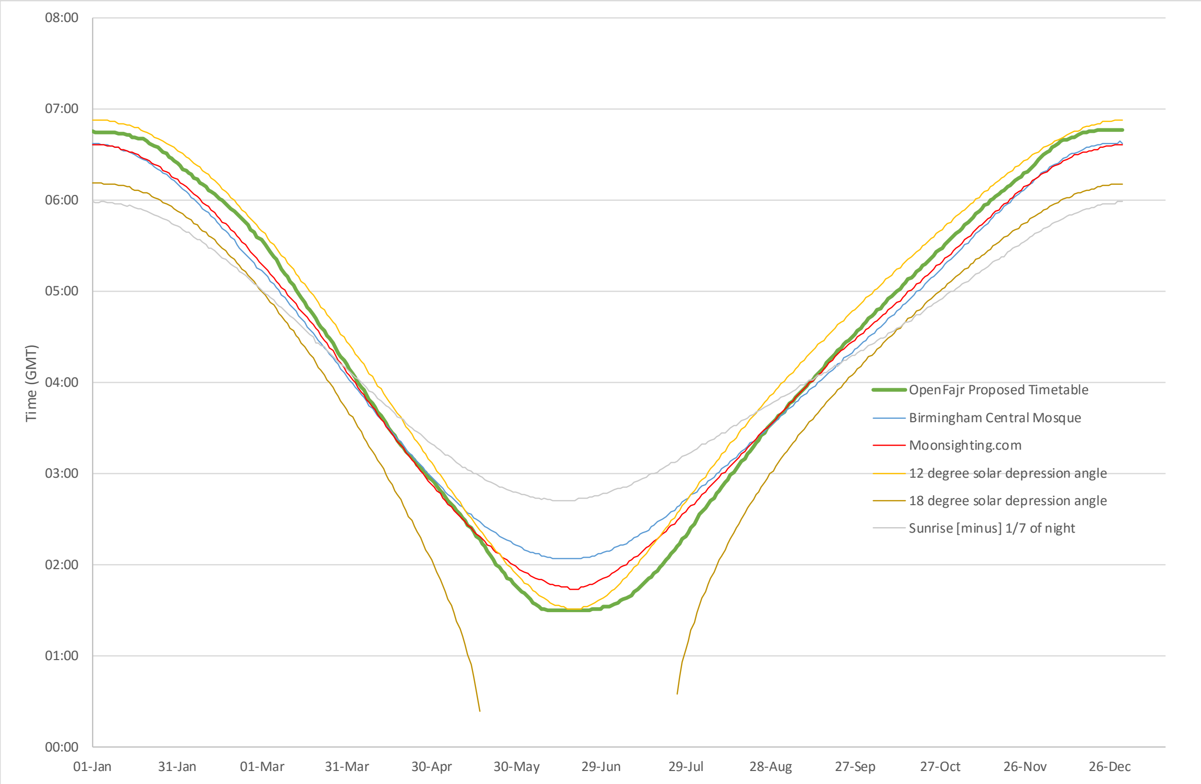


The LOWESS curve highlighted two issues. Firstly, with any best-fit curve, there were some data points below the curve, and some above. If the final timetable were to be based on the LOWESS curve only, the implication for this would be that for some dates, the proposed timetable may list a time a few minutes earlier than the consensus panel view of the time of fajr. Secondly, the LOWESS curve made a slight underestimate of the time of fajr in the winter peak, and a slight overestimation of the time of fajr in the summer trough.

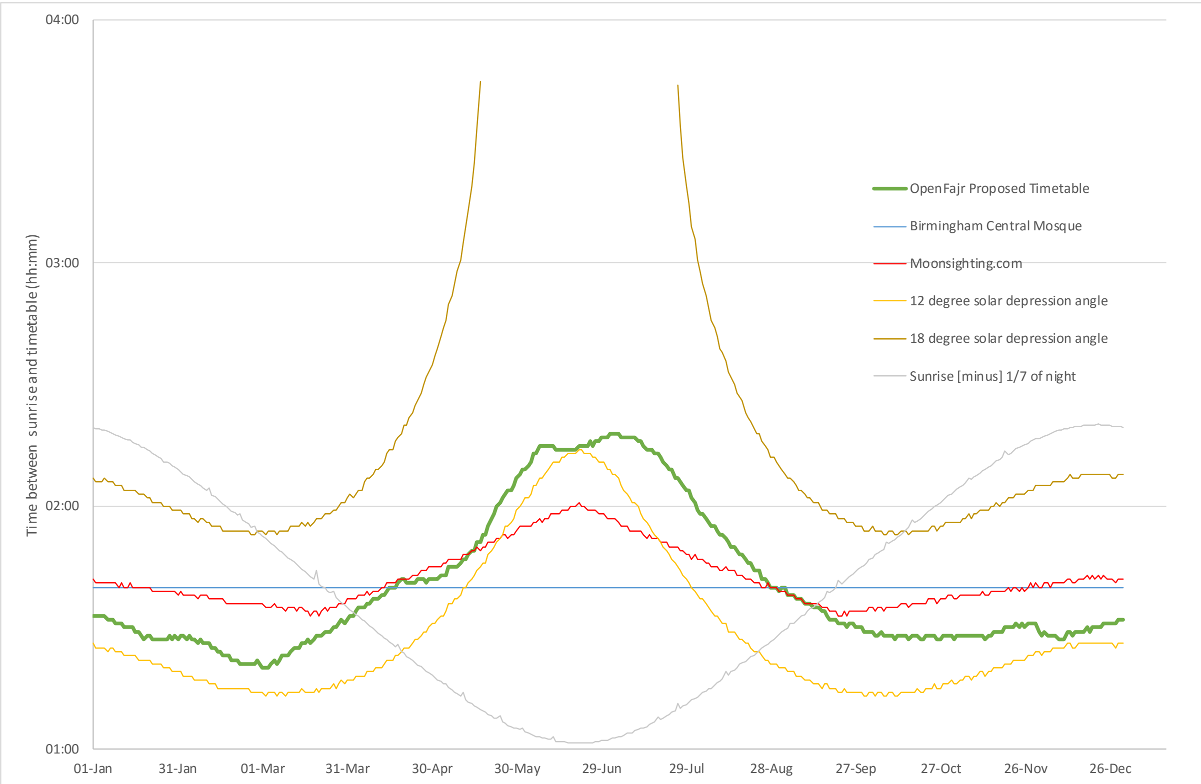
To overcome both issues, the difference between the consensus panel's opinion and the times determined by the LOWESS plot was calculated on a monthly basis, and the maximal positive difference between them was added to the time determined by the curve. Throughout the year, in the monthly bands, between 1 and 5 minutes were added, so that the adjusted curve never listed a fajr time earlier than the consensus panel opinion.

The full proposed timetable (in GMT) is listed in Appendix 1. Graph 2 demonstrates the OpenFajr proposed timetable, compared with other commonly-used timetables. Graph 3 shows the differences between sunrise and fajr times, amongst commonly-used timetables.

Graph 2:
OpenFajr timetable, compared with commonly-used timetables (GMT)



Graph 3:
Differences between sunrise and Fajr times, amongst OpenFajr timetable and commonly-used timetables (hours and minutes)



Discussion

Development, quality-assurance, and application of timetable

It is important that the eastern view of the horizon is clear when making an observation on the time of fajr. Our local climate poses a challenge to this, as the majority of days in any given year are likely to be cloudy. Even if continuous observations were carried out over a number of years, it may be that for some months only a few data points could be determined by observation alone.

It is possible to build a robust annual timetable, using 42 data points that span the seasons, by employing a validated statistical technique (the LOWESS method). Once we developed the timetable as discussed above, we then reviewed our locked database, which held the fajr times based on the OpenFajr team's analysis of the images, which were previously published on the website as suggested, non-validated times. Every one of these times fell within the proposed timetable and an 8-minute margin of error (discussed below). This quality assurance exercise further increases our confidence in the proposed timetable.

There are notable differences between the OpenFajr proposed timetable and other commonly-used timetables: for example, 35 minutes between the OpenFajr timetable and Birmingham Central Mosque's timetable in June; 14 minutes difference between the OpenFajr timetable and Moonsighting.com's timetable in December; and notable other differences throughout the seasons. This highlights the importance of the OpenFajr research objective: to aim to harmonise and unify the time at which the fajr prayer is conducted by providing accurate data.

As the relative path of the sun around the earth is annually recurrent (other than for the very small differences for which we use leap years to compensate), the proposed fajr timetable can be used recurrently in subsequent years. When the year is not a leap year, the time of the 29th February can be omitted. The 8-minute margin of error (discussed below) suitably mitigates for any small differences in years that have 365 or 366 days.

Margin of Error

The maximal difference between the adjusted curve and the consensus panel view of the times of fajr was calculated as 8 minutes: this is the margin of error of the proposed timetable, of specific importance when using the timetable to commence the fast.

Considering the factors that create the visual phenomenon of the first horizontal spread of light on the horizon prior to sunrise, with the light refracting and scattering in our atmosphere: the intensity of the first spread of light increases gradually, and will be subjectively discerned by different observers. It may be difficult for an observer to comment, once he/she is certain that the time of fajr has set in, that the time of fajr had certainly not set in just a second before: it is therefore difficult to consider the visual phenomenon at the time of fajr as a truly binary event. Based on the subjectivity of observations, and the expected variance in opinion when collating observer's perceptions, it is more realistic to consider a margin of error in any fajr prayer timetable, rather than someone using a timetable to consider that the time of fajr has certainly set in, and certainly had not set in a moment before.

We are therefore open and transparent about the expectation of a margin of error in any fajr timetable, although many timetables do not make reference to this. In our research project, sequential photographs were taken at 1-minute intervals, therefore, there will always be a 1-minute margin of error; and we explained above how the margin of error in the proposed timetable was calculated at a maximum of 8 minutes; this is a pragmatic outcome of an observational study. The practical implication for this is that based on the analysis of data, we have confidence in the proposed timetable that for all times given, the time of fajr has set in; but we cannot say that the time of fajr hasn't set in during the 8 minutes prior to the times given.

This issue is of specific importance when the timetable is being used by individuals or organisations during periods of fasting. Whilst we appreciate that a precautionary period between ending the pre-dawn meal and performing the fajr prayer is not universally applied, and similarly there is ḥadīth literature describing eating up until the point of the call to the fajr prayer, we also note there is ḥadīth literature describing a period between the end of the pre-dawn meal and the performance of the fajr prayer[13].

Having presented the data and evidence, we leave it to individuals and communities to decide how to apply this margin of error.

It may (or may not) be possible to reduce the margin of error, as we accrue more data.

Ambient Light *(see also addendum, page 13)*

An important factor when observing the time of fajr is the issue of ambient light: which could be due to light pollution; the lunar phase; the summer months when the solar depression angle is less [negative] compared to other seasons; or a combination of the above. We would like to discuss the issues of ambient light, as well as the perception of light by the human eye compared with the CCD detector, in further detail. Before doing so, it is important to highlight that our research is not simply observing a quantitative measure of light (e.g. lux or lumens) using a photometer, but rather the visual phenomenon of the first spread of horizontal light on the eastern horizon.

The human perception of brightness is not linearly proportional, but proportional to the logarithm of the quantitative measure of light[14]. Therefore, as ambient light increases, the ability of humans to discriminate between small differences in light intensity decreases (to phrase it another way, our ability to discern subtle differences in light diminishes as ambient light increases). This is because the rod photoreceptor cells on the human retina become "overexposed". When discerning subtle differences in light intensity, "observer bias" becomes more problematic when ambient light increases, due to multiple factors between different observers: different acclimatisation times to darkness; pupil diameters; visual acuities; opacities of the eye lens; proportion of rod cells to cone cells in the retina; the interpretation of images by the brain; and differing experience and training of observers. Therefore, as ambient light increases, the variance of human observation of the time of fajr increases. This is consistent with observer's reports: that some report being able to discern the time of fajr at the summer solstice when others can't; some can discern fajr at the middle of the lunar phase when others can't; and there is greatest variance of timetables in the summer months.

It is therefore important to highlight the differences of the perception of light between the human eye and a CCD sensor. As light enters the camera lens, as each photon hits the image sensor it causes the capacitor to accumulate an electric charge directly proportional to the light intensity. Therefore, even if ambient light increases, the camera continues to be sensitive to be able to discriminate between small differences in light intensities.

The camera is located 4 miles south of the city centre: therefore, the direction of sunrise is not over the city centre, and so light pollution is diffuse rather than focal. We have not seen any convincing evidence that the visual phenomenon of fajr is obliterated by diffuse light pollution; rather, in order to determine the time of fajr, we need a tool sensitive enough to discern it. In our appraisal of the data, fajr is discernible on the photographs, and the times corroborate with our observations beyond the city (where we acknowledge ambient light pollution will still be present, although reduced). Similarly, data points throughout the lunar phase match the curve of fajr times well; and also the first horizontal spread of light on the eastern horizon is discernible on the photographs in the peak of the summer, and these data points are congruent with data points before and after the peak of summer.

We therefore would like to present the case for the utility of using a CCD camera to discern fajr in our latitude (with increased eastern ambient light during the summer) and in the city (our camera is in a residential area, approximately 4 miles south from the city centre of Birmingham), and at different points throughout the lunar phase; and we have not seen any empirical evidence by which the data would be deemed invalid. However, to demonstrate CCD imaging as the "gold standard" to determine the time of fajr in our latitudes, we encourage similar research projects to collate comparative data from both

[13] Al-Bukhari: Volume 3, Book 31, Number 144
Narrated by Anas: Zaid bin Thabit said, "We took the Suhur with the Prophet. Then he stood for the prayer." I asked, "What was the interval between the Suhur and the Adhan?" He replied, "The interval was sufficient to recite fifty verses of the Quran."

[14] Weber–Fechner law

controlled observations and CCD images throughout the seasons, in different latitudes, and with different ambient light intensities (including light pollution levels and throughout the lunar phases), which will then enable a meta-analysis of photographs taken by CCD cameras.

Further Research

In view of the direct linear proportionality of the brightness of each pixel of the CCD images to the quantitative light measure, it is possible to use image differencing software to subtract ambient light from the set of images (using a control image from the same date), in order to enhance the contrast of the first spread of horizontal light on the images [as if a human eye was observing fajr without any ambient light] *(see addendum, page 13)*. Similarly, software analysis of the photographs could be employed to determine when the brightness of the spread of pixels [where fajr is observed] first increases; this technique could be used in combination with viewing the photographs, to mitigate against the human subjectivity of when the first spread of light occurs. We encourage researchers to use the library of photographs for further analysis.

In the same way that the CCD camera is being used to identify the time of fajr, the technique can be used to identify the reciprocal twilight time of ʿishā, and we encourage researchers to consider this too.

We intend to continue to accrue data, by mounting the camera at a different site, and we are currently exploring the suitability of sites on the eastern border of the city. We would value recommendations on suitable sites. As more data is acquired, we will publish the photographs on the website, and analyse them after a further calendar year. As the number of data points increases, the times of fajr may be iterated, and similarly it may be possible to reduce the margin of error. If a revised version of the timetable can be produced, it will be then disseminated. If the timetable is iterated, it is likely that any adjustments will be of no more than a few minutes.

Overall, we encourage researchers to mount similar CCD cameras in order to acquire more data, in our latitude and different latitudes [throughout the world], in locations with different ambient light levels, and spanning different atmospheric conditions, either under the OpenFajr umbrella or individually. It is also important to couple CCD photographs with direct [human] observations, under controlled conditions. Thereby, a large meta-analysis of the data could be undertaken, to not only produce accurate fajr timetables for many cities, but also to enable multi-regression analyses to determine the underlying equations that model the time of fajr accurately.

Recommendation

According to our literature review, the OpenFajr research project has produced the largest body of published observational data in our latitude. This has been analysed statistically in a robust process. Therefore, we propose the dissemination of this research paper to organisations and individuals for their critique, and for them to consider the adoption of the proposed timetable.

Prior to publishing the research, the full research paper was circulated for both expert-review and peer-review on 18/04/2016. The complete research paper including the proposed timetable was emailed to all members of the consensus panel, as well as those invited to join it, and posted to all 170 listed Islamic organisations and mosques in Birmingham, on 01/05/2016.

We pray that this research project serves to catalyse the unification of the Muslim community, through the unification of the time of the fajr prayer and commencement of the fast.

Acknowledgements

We would like to formally thank all members of the consensus panel, all supporters (both individuals and organisations) for their encouragement and positive feedback, the many correspondents for the enlightening dialogue, and the experts and peers who reviewed this research paper. We are also indebted to the site where the camera has been mounted.

<u>Appendix 1:</u>
<u>Proposed Fajr Timetable (in Greenwich Mean Time):</u>

(please note that the times in the summer months are not listed in British Summer Time)

Date	Fajr Time (GMT)
01-Jan	06:46
02-Jan	06:45
03-Jan	06:45
04-Jan	06:45
05-Jan	06:45
06-Jan	06:45
07-Jan	06:45
08-Jan	06:45
09-Jan	06:45
10-Jan	06:44
11-Jan	06:44
12-Jan	06:44
13-Jan	06:43
14-Jan	06:43
15-Jan	06:42
16-Jan	06:42
17-Jan	06:41
18-Jan	06:41
19-Jan	06:41
20-Jan	06:39
21-Jan	06:38
22-Jan	06:37
23-Jan	06:36
24-Jan	06:35
25-Jan	06:34
26-Jan	06:32
27-Jan	06:31
28-Jan	06:29
29-Jan	06:28
30-Jan	06:26
31-Jan	06:25
01-Feb	06:23
02-Feb	06:21
03-Feb	06:20
04-Feb	06:18
05-Feb	06:17
06-Feb	06:15
07-Feb	06:14
08-Feb	06:12
09-Feb	06:11
10-Feb	06:09
11-Feb	06:07
12-Feb	06:06
13-Feb	06:04
14-Feb	06:03
15-Feb	06:01
16-Feb	06:00
17-Feb	05:58
18-Feb	05:56
19-Feb	05:55
20-Feb	05:53
21-Feb	05:51
22-Feb	05:50
23-Feb	05:48
24-Feb	05:46
25-Feb	05:44
26-Feb	05:41
27-Feb	05:39
28-Feb	05:36
29-Feb	05:35
01-Mar	05:34
02-Mar	05:31
03-Mar	05:29
04-Mar	05:26
05-Mar	05:23
06-Mar	05:21
07-Mar	05:18
08-Mar	05:15
09-Mar	05:12
10-Mar	05:10
11-Mar	05:07
12-Mar	05:04
13-Mar	05:01
14-Mar	04:59
15-Mar	04:56
16-Mar	04:53
17-Mar	04:50
18-Mar	04:48
19-Mar	04:45
20-Mar	04:42
21-Mar	04:39
22-Mar	04:37
23-Mar	04:34
24-Mar	04:31
25-Mar	04:29
26-Mar	04:26
27-Mar	04:23
28-Mar	04:20
29-Mar	04:17
30-Mar	04:15
31-Mar	04:12
01-Apr	04:09
02-Apr	04:06
03-Apr	04:03
04-Apr	04:00
05-Apr	03:57
06-Apr	03:55
07-Apr	03:52
08-Apr	03:49
09-Apr	03:46
10-Apr	03:44
11-Apr	03:41
12-Apr	03:38
13-Apr	03:36
14-Apr	03:33
15-Apr	03:30
16-Apr	03:27
17-Apr	03:25
18-Apr	03:22
19-Apr	03:19
20-Apr	03:17
21-Apr	03:15
22-Apr	03:13
23-Apr	03:11
24-Apr	03:09
25-Apr	03:06
26-Apr	03:04
27-Apr	03:02
28-Apr	03:01
29-Apr	02:58
30-Apr	02:56
01-May	02:54
02-May	02:52
03-May	02:49
04-May	02:47
05-May	02:45
06-May	02:42
07-May	02:40
08-May	02:38
09-May	02:36
10-May	02:33
11-May	02:31
12-May	02:29
13-May	02:26
14-May	02:24
15-May	02:22
16-May	02:19
17-May	02:17
18-May	02:14
19-May	02:12
20-May	02:09
21-May	02:06
22-May	02:03
23-May	02:00
24-May	01:58
25-May	01:56
26-May	01:54
27-May	01:51
28-May	01:50
29-May	01:48
30-May	01:46
31-May	01:44
01-Jun	01:42
02-Jun	01:41
03-Jun	01:39
04-Jun	01:37
05-Jun	01:35
06-Jun	01:34
07-Jun	01:32
08-Jun	01:31
09-Jun	01:31
10-Jun	01:30
11-Jun	01:30
12-Jun	01:30
13-Jun	01:30
14-Jun	01:30
15-Jun	01:30
16-Jun	01:30
17-Jun	01:30
18-Jun	01:30
19-Jun	01:30
20-Jun	01:30
21-Jun	01:30
22-Jun	01:30
23-Jun	01:30
24-Jun	01:30
25-Jun	01:30
26-Jun	01:31
27-Jun	01:31
28-Jun	01:31
29-Jun	01:31
30-Jun	01:32
01-Jul	01:32
02-Jul	01:32
03-Jul	01:33
04-Jul	01:34
05-Jul	01:35
06-Jul	01:36
07-Jul	01:37
08-Jul	01:38
09-Jul	01:39
10-Jul	01:40
11-Jul	01:42
12-Jul	01:44
13-Jul	01:45
14-Jul	01:47
15-Jul	01:49
16-Jul	01:51
17-Jul	01:52
18-Jul	01:54
19-Jul	01:56
20-Jul	01:58
21-Jul	02:00
22-Jul	02:03
23-Jul	02:05
24-Jul	02:07
25-Jul	02:10
26-Jul	02:12
27-Jul	02:14
28-Jul	02:17
29-Jul	02:19
30-Jul	02:21
31-Jul	02:24

01-Aug	02:27	01-Sep	03:39	02-Oct	04:42	02-Nov	05:38	03-Dec	06:30
02-Aug	02:30	02-Sep	03:41	03-Oct	04:44	03-Nov	05:40	04-Dec	06:32
03-Aug	02:33	03-Sep	03:44	04-Oct	04:46	04-Nov	05:42	05-Dec	06:33
04-Aug	02:35	04-Sep	03:46	05-Oct	04:48	05-Nov	05:44	06-Dec	06:35
05-Aug	02:37	05-Sep	03:48	06-Oct	04:49	06-Nov	05:46	07-Dec	06:36
06-Aug	02:40	06-Sep	03:50	07-Oct	04:51	07-Nov	05:47	08-Dec	06:38
07-Aug	02:42	07-Sep	03:52	08-Oct	04:53	08-Nov	05:49	09-Dec	06:39
08-Aug	02:44	08-Sep	03:54	09-Oct	04:55	09-Nov	05:51	10-Dec	06:40
09-Aug	02:47	09-Sep	03:56	10-Oct	04:57	10-Nov	05:53	11-Dec	06:40
10-Aug	02:49	10-Sep	03:58	11-Oct	04:59	11-Nov	05:55	12-Dec	06:41
11-Aug	02:51	11-Sep	04:00	12-Oct	05:00	12-Nov	05:57	13-Dec	06:42
12-Aug	02:54	12-Sep	04:02	13-Oct	05:02	13-Nov	05:58	14-Dec	06:42
13-Aug	02:56	13-Sep	04:04	14-Oct	05:04	14-Nov	06:00	15-Dec	06:43
14-Aug	02:59	14-Sep	04:06	15-Oct	05:06	15-Nov	06:01	16-Dec	06:44
15-Aug	03:01	15-Sep	04:08	16-Oct	05:08	16-Nov	06:03	17-Dec	06:45
16-Aug	03:03	16-Sep	04:10	17-Oct	05:09	17-Nov	06:04	18-Dec	06:45
17-Aug	03:06	17-Sep	04:13	18-Oct	05:11	18-Nov	06:06	19-Dec	06:46
18-Aug	03:08	18-Sep	04:15	19-Oct	05:13	19-Nov	06:07	20-Dec	06:46
19-Aug	03:10	19-Sep	04:17	20-Oct	05:15	20-Nov	06:09	21-Dec	06:46
20-Aug	03:13	20-Sep	04:19	21-Oct	05:17	21-Nov	06:10	22-Dec	06:47
21-Aug	03:15	21-Sep	04:21	22-Oct	05:18	22-Nov	06:12	23-Dec	06:47
22-Aug	03:18	22-Sep	04:23	23-Oct	05:20	23-Nov	06:13	24-Dec	06:47
23-Aug	03:20	23-Sep	04:25	24-Oct	05:22	24-Nov	06:15	25-Dec	06:47
24-Aug	03:22	24-Sep	04:27	25-Oct	05:24	25-Nov	06:16	26-Dec	06:47
25-Aug	03:25	25-Sep	04:28	26-Oct	05:26	26-Nov	06:18	27-Dec	06:47
26-Aug	03:27	26-Sep	04:30	27-Oct	05:28	27-Nov	06:19	28-Dec	06:47
27-Aug	03:30	27-Sep	04:32	28-Oct	05:29	28-Nov	06:21	29-Dec	06:47
28-Aug	03:32	28-Sep	04:34	29-Oct	05:31	29-Nov	06:22	30-Dec	06:47
29-Aug	03:34	29-Sep	04:36	30-Oct	05:33	30-Nov	06:24	31-Dec	06:47
30-Aug	03:36	30-Sep	04:38	31-Oct	05:35	01-Dec	06:27		
31-Aug	03:38	01-Oct	04:40	01-Nov	05:37	02-Dec	06:29		

Addendum (September 2016)

Introduction

We decided to pose a supplementary research question, to determine if the presence of ambient light (specifically light pollution) influences the point at which fajr is determined on the CCD photographs.

For direct [human] observations, the *limiting magnitude* refers to the brightness of the faintest objects (such as stars) that can be seen, which is influenced by *sky brightness*. If it is assumed that the onset of fajr is less bright than the sky brightness, one could suppose that the time at which fajr is perceived by a direct human observation could be influenced by ambient light.

On page 9, we discussed the differences between the perception of light by the human eye, and a CCD sensor. Each photon that hits the CCD image sensor causes the capacitor to accumulate an electric charge, resulting in the brightness of each pixel of the photographs being directly proportional to the photons present.

Therefore, to consider the possible impact of ambient light upon the analysis of a CCD photograph, we posed the following research question: does the contrast of the first spread of horizontal light on the horizon against the background sky brightness influence the perception of fajr observed on the CCD photographs?

Method

We consulted with Dr Ali Dariush, an expert in CCD imaging at the Institute of Astronomy, University of Cambridge, UK, to formulate the method to answer this research question. As discussed in this research paper, because the CCD image sensor is highly sensitive[10], and because the brightness of each pixel of the photograph is directly proportional to the number of photons present, we used *image differencing* software[29] to 'subtract' ambient light from the photographs, with the goal of effectively simulating the sky without light pollution.

To do this, we selected series of photographs from the original dataset fulfilling the following criteria:

- the photographs spanned from a solar depression angle of 20 degrees (as no countries [or organisations we are aware of] cite a depression angle greater than 20 degrees to model the time of fajr)[7];
- there was no/minimal cloud cover throughout the series (as cloud cover, and hence its impact on the photographs, does not remain constant);
- the time of fajr determined by the consensus panel was not represented by a solar depression angle of either 15 or 18 degrees (as we wanted to test these two depression angles in addition to the OpenFajr time);
- the moon was not present around the time of fajr (as, once again, the position of the moon is not constant, hence its impact on the photographs does not remain constant).

All subsequent photographs in the series (from the same day) were subtracted from the photograph represented by the solar depression angle of 20 degrees. Therefore, if light pollution was present that day, it would have been removed from all subsequent photographs, assuming it remained constant over the time period in question (between 39 to 52 minutes).

5 mornings of images matching the above criteria were identified (27th February; 28th August; 23rd September; 26th September; 25th December); and from each day 3 sets of images series were shown in a data validation module with the timestamps removed and replaced with a letter, spanning the: 18 degree solar depression angle; the 15 degree solar depression angle; and the OpenFajr proposed time. The order of the 3 sets was randomised by a random number generator. All members of the consensus panel were contacted and invited to analyse the subtracted images, between the dates of 22/06/2016 and 17/07/2016, with their identity confirmed by a

[29] DiffImg v2.2.0

unique PIN code sent to them. For each of the 5 days, the three sets of image series were presented to them in a randomised order, and they were asked to identify the specific image which most accurately represented the first spread of horizontal light, or if they thought none of the images in any series represented the onset of fajr.

Results and Analysis

15 members of the original consensus panel (79% of the original consensus panel) accepted the invitation to complete the data validation module of the subtracted images. The results of all these data points were collated and the modal value was used to identify the time of fajr based on the subtracted images (just as it was previously done when deriving the OpenFajr timetable [see pages 5-7]). For all 5 days, fajr was consistently identified from the series of images spanning the original OpenFajr time, and not from either of the image series spanning the times represented by the 15 or 18 degree solar depression angles.

The fajr times identified from the subtracted images were statistically compared with the OpenFajr timetable using the sign test[30]. This demonstrated that there was no evidence against the null hypothesis (p[2-sided]=1.0000) that the differences between the pairs of observations equals zero. I.e., there is no evidence to reject the hypothesis that the fajr times of the original analysis and the fajr times of the analysis from the subtracted images are from the same distributions; therefore, no changes to the original OpenFajr timetable are proposed following this supplementary research.

Discussion

Subtracted images for the series without significant cloud cover are now available on the OpenFajr website[12] (35 series in total), with a key to indicate which control image has been used to subtract the subsequent images from. We invite their analysis.

We continue to present the case for the utility of CCD imaging, as pragmatic and workable means to empower Muslims to observe fajr in our regions, where 99% of the population in Europe live in a region with some degree of light pollution[31]. As already stated on page 10, we encourage researchers to acquire more data, in our latitude and different latitudes [throughout the world], in locations with different ambient light levels, and spanning different atmospheric conditions.

Prior to this addendum being made public on 25/09/16, we submitted it for peer-review and expert-review.

Recommendation for further research for the summer months

The demonstration of image subtraction highlights scope for further research in the summer months, when the sun's declination at night is less than in other seasons. We would value a multi-disciplinary forum where consensus can be reached on the definition of fajr amongst religious scholars, scientists, academics, astronomers and observers. The definition could be either: as the first distinguishable horizontal spread of light on the eastern horizon to the human eye (though an increase in eastern brightness may have occurred before, which may not be perceivable to the human eye, possibly in view of the rate of change of light due to the Weber-Fechner Law); or, the first spread of light following solar midnight (the point of lowest solar elevation), demonstrable through image differencing software by negating the eastern brightness in the summer by subtracting subsequent images from solar midnight (though this may not be perceivable ordinarily to the human eye in observations, or reviewing non-subtracted CCD images); or, a different definition of fajr in summer. To phrase it another way: does fajr occur when the human eye perceives the first horizontal spread of light on the eastern horizon through observation; or is the presence of light established by means other than by observation. The working definition

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[30] The sign test is a non-parametric statistical method to test for differences between pairs of observations that does not make assumptions about the nature of the distributions under test

[31] Falchi et al (2016): The new world atlas of artificial night sky brightness. Science Advances Vol 2, No. 6. http://advances.sciencemag.org/content/2/6/e1600377. Accessed online 04/08/2016

and results of the OpenFajr research study are based on the former definition.

As the rate of change of twilight may have significant impact on the perception of both fajr and ʿisha by observation in view of neural adaptation (and/or increment thresholds), we encourage researchers to explore this further.