Isha-based Regional Moonsighting

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Abstract: **The Islamic Calendar is based on lunar visibility. Many attempts have been made to realize an International Hijri Calendar to merge the dates of fasting and religious holidays among Muslim countries, based on the hypothesis of "unity of horizons". To validate fasting, the "common night" principle is stipulated, which necessitates global crescent visibility before local dawn. This paper introduces an *isha*-based approach with the argument of *tarawih* prayer time and shrinks the common night down to the midnight at most. Hereby a regional sighting concept with flexible dateline trimming and religious adherence has been offered.**

Keywords: lunar crescent visibility map; visibility separator parabola; Hijri calendar; International Date Line; International Lunar Month Line; Local Moonsighting; Global Moonsighting; Sunset Terminator Line; Dawn Terminator Line; tarawih prayer

1. INTRODUCTION

Time, the continued progress of existence, implies change and movement. The measurement of any time period necessitates a priodic motion. In the past, the delicate swing of a clock pendulum was employed for timekeeping; today, the piezoelectric characteristics of a crystal in an electronic watch or the oscillation of caesium-133 isotope in an atomic clock defines the elapse of time. In nature, however, many organisms are equipped with some kind of biological clock, synchronized with the day/night cycle. The sleep/wake loop is the common behavior related to the daily (circadian) rhythm, as emphasized in Quran (25:47): "*He is the One Who has made the night a mantle for you, and sleep a rest, and made the day to rise up again*". Monthly (circalunar) rhythms are also widespread among animals, especially in the context of reproduction.

Although the day is the consequence of the Earth's spin and the month is the outcome of the rotation of the Moon around the Earth, Quran (21:33) mentions instead the Sun and the Moon: "*And it is He Who created the night and the day, and the Sun and the Moon. They float, each in an orbit*". The probable reason is that the daily cycle, as we perceive, is caused by the apparent cyclic precession of the Sun over the sky. The diurnal trajectories of both the Sun and the Moon are not quite circular, but rather spiral, such that each rise/set point (horizontal up/down crossing) happens slightly different (Figure 1). As such, the Sun makes yearly oscillations on the sky, whereas the Moon vibrates monthly.

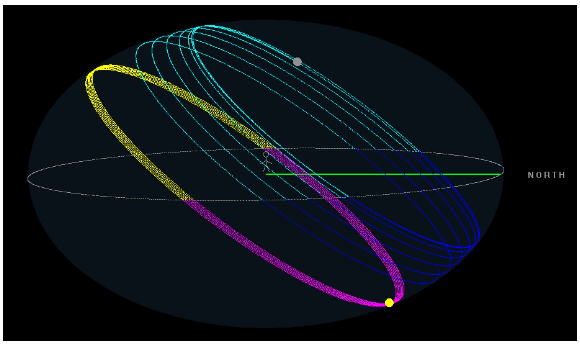

Figure 1 – Typical Weekly Sun/Moon Trajectory

Similar to the Moon or the Sun, motions of celestial bodies are inherently helical, caused by the superposition of higher rank orbits; from satellites to planets, from the stars to galaxies. A philosophic analogy could also exist for life cycles, either of the human being or the cosmos.

The Sun and the Moon are such the basic (or natural) timekeeping elements for the mankind, as emphasized in Quran (10:5): "*It is He Who made the Sun to be a shining glory and the Moon to be a light [of beauty], and measured out stages for it; that ye might know the number of years and the count of time*". The obvious need for computing and counting the time (days, months, years) brings about the use of calendars, both the solar and the lunar.

2. SOLAR CALENDAR

2.1 Time Zones

The inclination of the trajectories as well as the position of the Sun or the Moon on its sky-path depends on the site of the observer. That's why the rise and set times change both with time & location. A day of an ordinary individual is the time span between his wake-up and go-asleep so the disturbing changeover of the calendar day should be better performed during the middle of the night, when the social activity is minimum. Our clock system hence resets from 23:59 to 00:00 at mean midnight and the date is incremented at this time. Midnight sets in when the Sun's elevation is at minimum (lower transit, see Figure 1). As the Earth revolves around, the midnight occurs at locations (longitudes) exact opposite to the Sun, i.e. 180° apart from the zenith meridian. Every four minutes, the midnight meridian (local dateline) sweeps westward by one degree of angle. This dependence of the midnight time to the observer's position necessitated the use of time zones for convenience, such that the local time expressed by anyone on Earth follows roughly the local day/night cycle. This way, noon for example occurs around 12:00, whether in Asia or America, or people start work about 9:00, in Africa or Europe.

Time zones are generally built for every hour; i.e. they are 15° wide in longitude. The time zone borders, however, don't follow the meridian lines exactly; they are adjusted for political reasons. With the use of the time zones, the local dateline is no more the mean midnight meridian; instead it becomes the right-side border of that time zone it stays on. At the beginning of every hour, the dateline jumps to the adjacent time zone border on its left (to the west). So the local times are in fact not purely local, but rather regional.

2.2 International Date Line

Since this process is continuous, a reference point, or a marker meridian is needed to increment the day number and thus establish an international calendar. This is similar to put a sign on a wheel to count its revolutions at every crossing. The International Date Line (IDL) is such an imaginary bar on Earth's surface defining the boundary between one day and the next. It runs from one pole to the other and divides the Earth into the Western and Eastern Hemisphere. The annoying fact with this reference line is that the date will vary on its opposite sides, although the local times remain close; a city just to the east of the IDL will have a time only one hour ahead of its neighbor to its west but still one day behind. The solution for this unavoidable discontinuity problem is to put this global dateline onto a very sparse populated section of the Earth. IDL was therefore placed in 1884 on the Central Pacific Ocean (Figure 2). The line opposite to IDL is the Greenwich (prime) meridian, which is implicitly accepted as the middle of the global main population; so the international (global) date will be progressed whenever the Greenwich Mean Time (GMT) crosses 12:00.

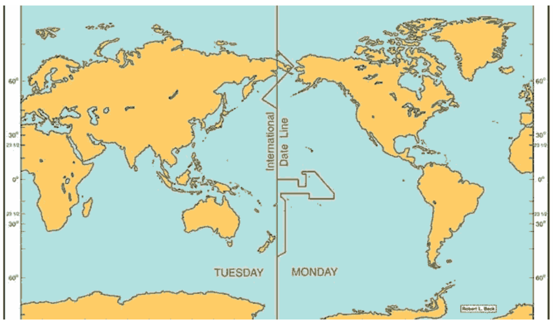

Figure 2 – International Dateline

As to summarize:

- Sunset/sunrise and transit times are local, just are the prayer times.
- The local time is expressed in regional, where the common region is the area of the related time zone. The daily prayer times are thus declared also in regional, regarding the worldwide solar calendar.
- At any time, there are at least[1] two different dates valid on somewhere of the Earth, inevitably.
- IDL has been chosen arbitrarily for convenience to allow an International Solar Calendar.

3. LUNAR CALENDAR

Although a calendar is basically a system to organize the time for administrative, social and commercial purposes, it may have also religious aspects. A lunar calendar in this respect is crucial for Muslims, since worships like the fasting and pilgrimage are regulated according to specific lunation. In contrast to the solar calendar, which defines the transition of the date at the midnight, a new day always begins with the start of the night, i.e. at sunset, in Islamic tradition. At any time on Earth, the midnight for the solar calendar occurs vertically at some meridian, whereas the sunset border for a lunar calendar is inclined, following the declination angle δ_S. Figure 3 is the prayer timing map for 00:25 GMT of June 4^{th}, 2019 and the orange/blue border on the left stretches over the places of sunset. This boundary is named as the Sunset Terminator Line (STL) [1], which separates the Islamic date; locations to the right of this line have just entered the next day. As such, it is not possible to assign a certain longitude for the Islamic local dateline, unlike the solar local dateline (mean midnight meridian), which is shown as a red vertical bar in Figure 3.

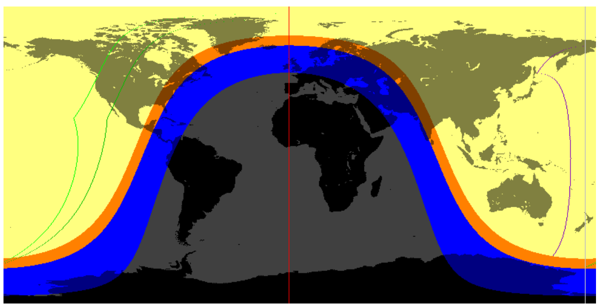

Figure 3 – Prayer Map for 00:25 GMT of June 4^{th}, 2019

[1] Every day between 10:00 and 11:59 GMT, three different dates on the calendar are in use at the same time on Earth because of the curls on IDL.

STL skips the geographic poles, where the Sun either does not rise or not set. This causes a problem for the determination of the religious day at higher latitudes. A possible solution to this matter would be to assign a minimum day/night interval, as applied for the calculation of prayer timings [2]. This method is briefly explained in Section 4.4.

3.1 Start of the Lunar Month

A new lunar month will start upon the initial perception of the thin crescent shortly after sunset, following the dark (black) moon period, as per *hadith*: "*Fast when you see [the Moon] and cease fasting when you see, and if it is hidden or cloudy, complete [the month] to thirty days*" (*Abu Huraira*). Most scholars relying on this *hadith* in a strict and literal manner claimed that the only way to accept the onset of a new month is a physical naked-eye observance of the maiden crescent and that astronomical calculation cannot be accredited. The Quran verse (2:185) "*those of you who witnesses the month must fast in it*" was further interpreted as to support the denial of calculation.

On the other hand, this latter verse was also commented as: "*every one of you who is present [at his home] during that month should spend it in fasting*", in favor of computation. The verse (55:5) "*the Sun and the Moon follow courses [exactly] computed*" and the *hadith* "*do not fast unless you see the crescent [of Ramadan], and do not give up fasting till you see the crescent [of Shawwal], but if the sky is overcast, then estimate*" were additionally argued to promote the permission for calculation. This evaluation is mainly based on the opinion that the real objective of "witnessing the month" (not the crescent) should be "certainty of knowledge" [3] [4].

Regarding the use of calculation, it will be adequate to remind that the start of a lunar month resembles the *fajr* & *isha* prayer times, which are bound to the dawn and dusk, respectively. Since the phenomenon of twilight depends on atmospheric conditions, the naked-eye observation time of their onset cannot be precisely computed [2]. Therefore, the estimation is performed by taking "safe" values for the relevant parameters, deduced from an observational database. Since the calculated *fajr*/*isha* times are accepted by the vast majority of Muslims today, there should be no resistance to a similar computational method for the visibility of the lunar crescent.

3.2 Local Moonsighting

Another debate is about the locality of the moonsighting. Local sighting requires that the crescent is genuinely eye-witnessed in the town; the start date of a month will then differ among the districts with respect to the observation results. Local sighting is also known as the "variety of horizons" or "multiple horizons" (*ikhtilaf-ul-matali'*). The late jurists, including Imam al-Qarrafi, ruled this opinion, against the established positions of their religious schools [4]. Their basic evidence is the verse (2:185): "*Those of you who witness this month shall fast therein*". Besides, the plural form (*ahillah*) in the verse (2:189) "*They ask you, [O Muhammad], about the new [crescent] moons. Say, –They are measurements of time for the people and for Hajj*" has been interpreted as: "*every region with their own [phase of the] crescent moons*". Moreover, the *Kurayb hadith*, where the report of sighting from Damascus was not used by Ibn Abbas for Medina, should be a valid proof for the local moonsighting approach. Considering the difference of horizons, the start of a lunar month has been held similar to the difference of local prayer times.

In the tightest sense of this concept, where each observer would depend on its own observation, no unity could be established even within the smallest perimeter; therefore a minimum area should be assigned for the size of the common horizon. Imam Shafi is reported to have accepted cities whose boundary is within the *qasr* distance (48 miles) of the city which have sighted the crescent [5].

3.3 Visibility Curve

The detection probability of the very new crescent has been worked since the Babylon age. Various parameters related to the lunar visibility have been investigated by many observation campaigns and there are plenty of data available. Many empirical and photometric models are propounded, based on or tested against the available sighting database.

Common to any statistical result, the suggested models express a confidence limit; in other words they include a deviation factor of $\pm\sigma$. Meteorological conditions, observer abilities and model-induced errors all contribute to this value of uncertainty. Therefore, unless the calculated probability value remains within the uncertain region, it may be quite definitely claimed that the crescent can/cannot be testified locally, as long as the sky is clear. A lunar visibility criterion can hence eliminate positive errors of testimony, such that any report of sighting with a calculated visibility value lower than $-\sigma$ can be discarded. Since the thin crescent stays visible only for a limited time span over the horizon, those criteria which are further able to express the instantaneous visibility as a function of time become more beneficial as to know the visible period. Verification against this visibility interval should help to enhance the reliability of the observation result[2]. Frankly, the amount of positive errors may become considerably high; during a sighting campaign (Moonwatch-5), the fractional rate of positive errors happened to be 3 out of 20, namely as high as 15% [6]. Another analysis for years between 1963 and 2000 indicates that there are even 41 "impossible sightings" out of 115 observations (36%), in terms of angular separation [7].

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2 The Extended Crescent Visibility Criterion has this capability.

Since the lunar visibility depends on the location, the probability is to be checked for every latitude & longitude of the Earth (each pixel), in order to obtain a crescent visibility map. Such a map will distinguish the areas where the crescent is visible (probability greater than a threshold value) from the areas where the crescent is not visible (probability less than a threshold value) for the first night of the new month. The discrimination border resembles a parabola growing to west. Its apex is the global Point of First Visibility (PFV) for the specific lunar month. Note that this visibility curve is not a Sunset Terminator Line; it does not display the time-dependent lunar dateline, but rather it defines the date zone of the new month. Figure 4 shows the naked-eye visibility map for the 1st of Shawwal 1440. The green-yellow belt represents the uncertainty zone for sea-level, whereas the yellow-orange area depicts that for 1,000 m altitude. Probability spread is about ±1° in Sun altitude, translating into an uncertainty region of ±30° in longitude [8]. Within the blue region in the map, the crescent is expected to be certainly[3] visible within a narrow time on that evening, whereas the Moon cannot ever be spotted in the gray region during that night.

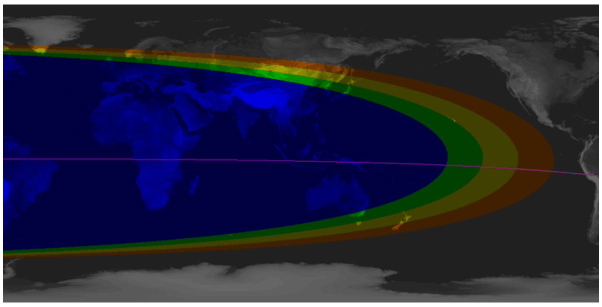

Figure 4 – Lunar Visibility Map for Shawwal 1440

3.4 International Lunar Month Line

A lunar visibility Earth map, based on certain criteria, will estimate the start of a lunar month for each local position and hence the visibility parabola on that map becomes the International Lunar Month Line (ILML), regarding the Local Moonsighting approach. While the solar dateline divides the Earth into different solar days, the lunar month line splits it into distinct lunar months. To the west of ILML, the crescent is visible and the lunar month starts at that local night; whilst to the east of the ILML, the crescent is not visible and the new lunar month does not start until the next evening.

The drawback with Local Moonsighting is that the lunar visibility parabola cuts across country and continent boundaries and is not bound by longitudes or latitudes either. Furthermore some locations, especially near geographic poles, may experience lunar months less than 29 days or more than 30 days, because ILML starts at a different point every month and its shape (angle of arms) changes slightly each time. Since it takes 2, 3 or even more solar dates for the lunar visibility to cover most of the globe, the high-latitude areas will enter the month several days later than the majority of world. The Moon may even be totally invisible for many days or weeks in polar zones, which is similar to the problem of daily prayer timings.

3.5 Global Moonsighting

The early Islamic scholars deduced "unity of horizons" (*ittihad-ul-matali'*) from the *Abu Huraira hadith* given in Section 3.1. To many of them, the entire Muslim world is obligated to begin fasting if the new Moon is sighted anywhere in the world [4]. Another proof is the occasion when the Prophet accepted news from a distant place: "*Narrated Ikrimah: –Once the people doubted the appearance of the Moon of Ramadan, and intended neither to offer the tarawih prayer nor to keep fast. A Bedouin came from al-Harrah and testified that he had sighted the Moon. He was brought to the Prophet… He commanded Bilal who announced to the people to offer the tarawih prayer and to keep fast*" (*Abu Dawud*).

It should be considered that during the era of the early religious schools, the communication capabilities were much limited and the Muslims occupied a limited region of the world, such that a testimony of the young crescent could be spread over a small neighbor region only, where the night should have entered shortly before. Nevertheless, the Muslim population is now distributed all over the world. So, from an astronomical standpoint, it is impossible to implement Global Moonsighting today; simply because e.g. by the time California sights the crescent, it is already next day morning in Japan, which is too late to start fasting [9]. For that reason, a Global Moonsighting can merely be valid as long as the *fajr* (dawn) has not entered yet when the first global visibility of the new Moon starts. That's why in the Kuwait Islamic Conference 1973, it was concluded that "difference in horizons" is to be disregarded even amongst countries separated by long distances, as long as they share any part of the night, no matter how small this part is.

The common area "sharing the same night" covers the right side of the visibility parabola and the left side of the "Dawn Terminator Line" (DTL) at the time of the initial global visibility. DTL separates the Islamic night from the day; it is the divider line for the onset of fasting, or the ultimate end of *isha* time. In Figure 3, DTL is drawn as the gray/blue border to the right of the red local solar dateline. By comparing Figure 3 and Figure 4, the allowable region for the Global Moonsighting can thus be deducted as the continents of America, Africa and a tiny portion from Eurasia. This is the maximum section of the Earth which can be included into the

[3] The term "certainly" is valid for a clear sky with experienced observers having good visual acuity.

"united horizon". Figure 5 indicates a combined map, where DTL is displayed as the violet/red boundary. The largest permitted common field is then the sum of regions colored in gray, cyan, olive and violet. *Isha* has already ended and *fajr* entered within the red space, so there must be awaited another day.

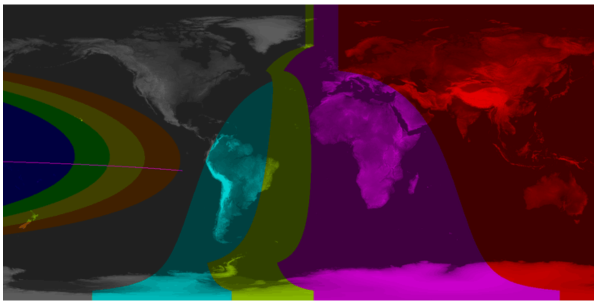

Figure 5 – Combined Map for Shawwal 1440

The annoying discontinuity with the dateline, which is the existence of different days on the adjacent sites opposite of the IDL, appears in a similar manner for the case of ILML. In fact, the Global Moonsighting is a search for the elimination of this leap. In the solar calendar, it was solved by freely placing the IDL onto the uninhabited ocean; however the ILML is dictated astronomically and its position differs for every lunation. The "common night" concept seems just to shift the ILML to the right; now DTL becomes the ILML instead of the visibility curve. This measure may help in some cases, especially when the vertex of the visibility parabola lies near the Prime Meridian (Greenwich), such that DTL is positioned on the Pacific Ocean, in the vicinity of IDL. Then the most of the population (except the red zone) can be added into the common date, as mapped in Figure 6.

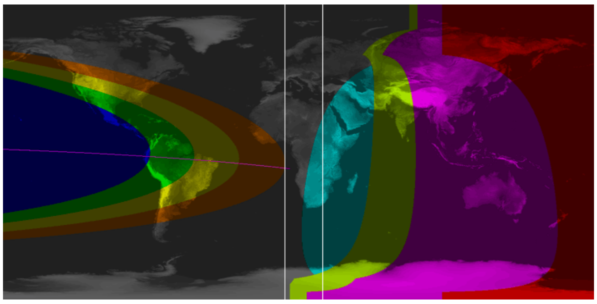

Figure 6 – Combined Map for Ramadan 1441

Yet, it may also disrupt the unity which could be achieved with the Local Moonsighting. A typical example is the end of Ramadan 1440: Regarding the local sighting, the ILML (visibility curve) stays within the ocean (Figure 5) to the left of America; hence it was appropriate to begin Shawwal worldwide on the 5th of June, 2019. But sticking on the global sighting, 18 countries started Shawwal one day before[4] on the 4th, despite the crescent was not reported to be seen on anywhere of the world in the evening of the 3rd.

The main goal today is the unification of the global Islamic calendar, i.e. its synchronization to the solar calendar, such that a common Gregorian start date can be assigned to each lunar month. This way, a universal Gregorian/Hijri calendar converter, independent of the geographic location, could be established, especially for administrative and political purposes. Such a unified calendar is also named as "single-zone" calendar, since the entire world is assumed as a monolithic horizon. In this case, the ILML will coincide with the IDL. Many proposals have been formed to achieve a common calendar:

- Istanbul Islamic Conference, in 1978, states that all countries over the world will use the same Unified Hijri Calendar, so the new month will start on the same date at the local sunset. The first day of a lunar month will be the Gregorian day following the day on which the new Moon becomes visible, i.e. the Sun-Moon elongation (ARCL) reaches 8º (Danjon limit).
- Jamaluddin Abderrazik, in 2004, preferred to test whether the conjunction occurs before 12:00 GMT [10].
- Same way, Khalid Shaukat suggested in 2006 a Global Islamic Lunar Calendar as: If the conjunction occurs before 12:00 UTC, the Islamic month begins at sunset of that day everywhere in the world; the next day otherwise [11].
- Abdul Halim Abdul Aziz and Ahmed Kamil Ahmed proposed in 2014 a Unified Islamic Calendar, where the crescent visibility is tested (illumination $I \geq 0.39\%$) for the 60°W longitude and 25°N/S latitude [12].
- David L. McNaughton offered in 2015 a World-Wide, Predefined Islamic Calendar, where the criterion is that the Sun-Moon elongation exceeds 12° when the civil dusk commences at 0ºN/180ºW [13].
- Omar Abur-Robb defined in 2017 the "Hijri Date-Line" HDL as the STL at a point opposite to Mecca in its latitude line for the time 19 hours following the conjunction, determined as the first global visibility [1].
- The Umm al-Qura calendar adopted by Saudi Arabia asserts the conjunction to occur before the sunset and the moonset eventuates after the sunset in Mecca.

There are still plenty of other presentations for a unified (single-zone) calendar. In 2016, the International Congress of Hijri Unity Calendar took in Istanbul, where is decided that a calendar correction will be performed if ARCL reaches 8º

[4] Crescent Observation Results for Shawwal 1440, the Islamic Crescents Observation Project (ICOP).

shortly after 00:00 GMT, in case particular conditions are met [10]. It is not the scope of this paper to analyze and comment on the various suggestions for a Unified Hijri Calendar, simply because none of them can ensure both the "naked-eye visibility" and the "common night" criteria globally at the same time, owing to the roundness of the Earth. Therefore any claim of single-zone Global Moonsighting will result in faults (mismatches), more or less, in two ways:

Positive faults in western (west of the visibility parabola), where certain areas are enforced not to begin fast, although the crescent has been locally observed; or negative faults in eastern (east of DTL), where some regions are obliged to fast, despite the *isha* is over and *fajr* already entered. The "common night" between the visibility curve and the DTL is about ten hours, which corresponds to a longitudinal width of ca. 150°. The probability of a fault to occur each month will then be equal to (1 – 150 / 360), or 58%. Indeed, an analysis for 87 lunar months gives the ratio of positive faults as 30% and negative faults as 29%, summing up to 59% [14].

The rule asserted in 1978 Istanbul Conference has very little positive faults because at midnight Greenwich the Sun sets roughly at longitude 90°W, west of which resides the Pacific Ocean. Since the maiden crescent can only be seen shortly after sunset, it will not be perceivable in America after 00:00 GMT. That's why it is effective to use this rule to find the first Gregorian date of a lunar month. Areas with negative faults will then admit the following day. Hence we recommend sticking on this rule for the implementation of an administrative (not religious) International Hijri/Gregorian calendar converter.

3.6 Regional Moonsighting

Findings from the investigation of both the Local and the Global Moonsighting can be listed as:

- Under the pure local sighting, ILML is most westward, aligned with the visibility curve, which is neither bound by longitude nor by any political boundary.
- Local sighting is not applicable at higher latitudes because of multiple-day delays or lunar non-visibility.
- Along with the widest global sighting possible, where there exists no religious fault within the common night, ILML is most eastward on DTL, which is neither bound again by longitude nor by any boundary.
- Neither the local nor the widest complying global sighting alone can assure an ILML, which is adjustable for political or geographic borders, like the time zones.
- The absolute (single-zone) Global Moonsighting is an intentional overlap of the ILML with the IDL, based on various criteria. This measure is useful to sync both the Islamic and the Gregorian calendars; nevertheless, it is not religiously appropriate for statistically more than the half of the world.

The above statements indicate that an exact local or exact global sighting is not suitable; there must be some limited mutual region, in which the lunar date is identical. As such, the local & global sightings practically converge into the Regional Moonsighting, where the ILML is positioned somewhere between the visibility curve and the DTL. The term "locality" describes the width of this region; as the locality increases the region decreases and vice versa. The maximal locality is achieved with the most westward ILML (visibility curve); the minimal locality exists under the most eastward ILML (DTL). The absolute (single-zone) Global Moonsighting may be named as the "zero locality".

So now the task will be the determination of the ILML position, or the amount of locality, together with some relevant criteria. The placement process of the regional ILML may be categorized into two, namely "static" and "dynamic":

3.7 Static ILML

Static positioning requires permanent zones, just like the time zones. For each lunation, the border of either zone becomes the ILML, according to some specific rule. Commonly there are two- or three-zoned approaches:

- Nidhal Guessoum propounded a dual-zone calendar. The western zone consists of the American continents and the eastern zone includes the rest [10]. If the conjunction happens before the local dawn in Mecca, both zones start the lunar month that evening, i.e. the ILML matches the IDL. Otherwise if the conjunction occurs before 12:00 GMT, only the western zone begins the month at that evening. Positive faults are declared to be as low as 1.7%, whereas the negative faults sum up to 25% [14].
- Odeh proffered a similar bi-zonal calendar, named as the Universal Hejric Calendar (UHC). The western zone is again comprised of the American continents and the remaining part is the eastern zone; but now the border is explicitly declared as the 20°W longitude. The new lunar month shall begin on that zone, if there is a possibility of visibility, either by naked eyes or by optical aid, on any land portion of this zone, as calculated per the visibility criterion. This method seems to produce fewer faults, exclusively near the polar far-east or on Australia/New Zealand region. A typical example would be Ramadan 1441 (see Figure 6); the eastern zone starts the month because of the small portion of visibility in Africa (orange) although dawn has already commenced in the Pacific area (red).
- While keeping the American continents as a unique zone, Ilyas divided the eastern zone into two distinct

regions, namely the Africa/Europe/West-Asian zone and the Australia/Pacific/East-Asian zone [15]. The visibility is to be computed for each region separately. Reminding the 150° longitudinal width of the common night, this tri-zonal calendar is supposed to work without any fault for land territory.

3.8 Dynamic ILML

Under this grouping, the zones are flexible and ILDL will be placed smoothly according to the relevant criterion. Dynamic-region sighting is hence always bi-zonal; ILDL sects the world into the western part and the eastern part, the former being one day ahead of the latter. Two renowned applications of dynamic zoning are explained below:

- Qudah proposed that if the crescent is visible anywhere on a meridian, then every location on the same longitude or to the west is included into the common zone. In other words, ILDL will be the meridian where the vertex of the visibility parabola resides, as detailed by Jawaid [16]. According to this principle, the white vertical bar on the left in Figure 6 is the ILML for Ramadan 1441, which is located at 5°E, namely the longitude of the global Point of First Visibility (PFV). This ruling assumes that the probability of visibility does not depend on the latitude, which is not quite correct. Figure 7 shows the instantaneous visibility for Ramadan 1441, captured at 3 hours after the Time of First Visibility. The border of the visibility area, painted in red, represents an iso-probability line. It is not vertical but rather parallel to STL, i.e. inclined at the declination angle δ_s. Nevertheless, this calendar makes it possible to assign a definite longitude for ILML, just like the IDL. The obvious drawback however is that this ILML crosses the political borders, the same way with the visibility parabola. Yet, Jawaid claims that some adjustments can be made around PFV, just as the case of IDL, if political or regional contiguity demands.
- Qamar Uddin offered a Regional Moonsighting criterion in 2017 [17] : UK Muslims should not extend the boundaries of sighting news from abroad any more than 1.5 hours to the west within the same hemisphere, which is equivalent to 22.5° longitude. This time span of 90 minutes stems from the sunset-dusk interval. The reasoning is based on the *Abu Dawud hadith* in Section 3.5 such that the maiden crescent is visible just after sunset and the Bedouin with the news should have come from the near outside until the *isha* time in Medina. Although it is specific for the UK and hence designates a local (static) region, it can be applied as a general dynamic rule by extending the common region 22.5° further to the east of PFV (white vertical bar on the right in Figure 6). ILML can then be placed anywhere between the visibility curve and this limit. The UK, being narrow in longitude, fits en bloc into this region such that it is possible to assign a unique lunar date.

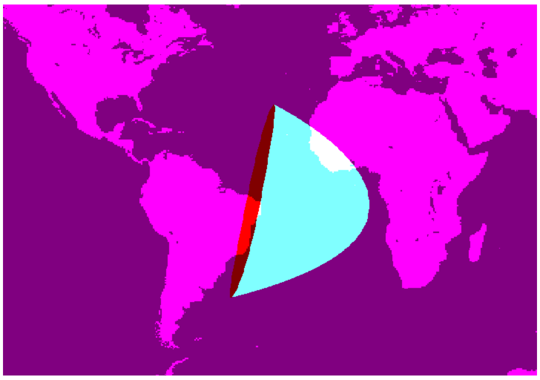

Figure 7 – Instantaneous Visibility Map for Ramadan 1441

4. PROPOSED METHOD

Regional Moonsighting proves to be more efficient compared to local or global sighting. Dual static zoning passes the ILML through the oceans, either the Pacific or the Atlantic, such that there are no neighboring land pieces with different lunar dates. However it may contain religious faults. On the other hand, dynamic and tri-zonal static techniques, though faultless, cause adjacent countries to begin the lunar month on consecutive days.

By definition, the negative fault comes out when the initial crescent arises globally after the local daybreak, which is a breach of the common night principle. Actually, this principle originates from the *ahadith* about fasting; commence of the other Islamic months is thus based on Ramadan.

4.1 Issue of Tarawih Prayer

Other than fasting, the *tarawih* prayer was a continued practice of the Holy Prophet, which is disregarded in general concerning the religious compatibility. *Tarawih* is performed right after the *isha* prayer, upon the onset of the Ramadan. But since the first night of Ramadan begins with the observation of the crescent following the dark moon period, *tarawih* can only be prayed after the physical witness or any sighting news. This matter is usually overlooked currently.

Therefore when considering the *tarawih* prayer, the fault (or religious nonconformance) should be redefined as “the global visibility after the local *isha* time”. This is because we don’t know any *hadith* saying that the *tarawih* was postponed to wait for possible sighting information.

4.2 Isha Terminator Line

The preferred east border of the proposed region will then be the divider line for the onset of *isha*, or the "Isha Terminator Line" (ITL), which intersects the gray and cyan areas in Figure 5 and Figure 6. This approach is in line with the offer by Qamar Uddin; however the vertical bar 22.5° east of PFV is now corrected in inclination and replaced by the real *isha* discriminator (see Figure 6). Again, any fine adjustment of the ILML within the gray zone to ensure unity of calendar throughout a country is allowed. It can also be deducted from Figure 6 that an ILML on the meridian of PFV as propounded by Jawaid resides to the left of ITL, thus providing the preferred condition of "visibility before *isha*".

4.3 End of Isha (½ or ⅓ of the Night)

In a *hadith* about the time slot of each prayer is told that "*there is a beginning and an end of the time of each prayer… The time of the isha (night) prayer is when the twilight disappears, up to the middle of the night…*" One other narration notifies the end of *isha* as "*one-third of the night*". Accordingly, *tarawih* should rather be finished before the midnight or the first third of the night. Indeed, the *tarawih* prayer is known to be performed in the first half of the Ramadan night [18]. So it is permitted to delay *isha*/*tarawih* prayer until either ½ or ⅓ of the night, which becomes *makrouh* thereafter. Hence it may be permitted to widen the common region as to include those areas where *isha* has already set in but the first third or half of the night has not expired yet. This is useful to cover the whole continent or a wide country. The cyan zone in Figure 5 and Figure 6 encompasses the time span from *isha* to ⅓ of night, whereas the olive region contains the interval from one-third to midnight. Note that the (religious) night here is admitted as the period between the sunset and the dawn.

Relating the cyan & olive fields, the important subject is that the crescent is not yet distinguishable at the local *isha* time and the *tarawih* prayer should thus be reprieved until the sighting news has been received or until the calculated global visibility time has reached.

4.4 Handling of Polar Zones

In order that the day and night can be defined in polar zones and hence a regional zone encircled, the terminator lines STL, ITL and DTL must be somehow stretched to include the higher latitudes.

One practice is to restrain the shortest (astronomical) day and the shortest (astronomical) night to three hours, thereby leaving a sufficient interval to perform the prayers. As such the span between the sunset and sunrise will not be less than 180 minutes. Accordingly, the shortest day in winter will begin (latest sunrise) at 90 minutes before noon (zenith) time and it will end (earliest sunset) 90 minutes after the noon (upper transit). Inversely, the shortest night in summer will begin (latest sunset) at 90 minutes before (astronomical) midnight time and it will end (earliest sunrise) 90 minutes after the midnight (lower transit). Obeying this rule, STL will be sketched to be at least 22.5° and at most 157.5° away from the zenith.

Concerning the *fajr* for latitudes over 49°, where the twilight persists in summer and onset of the dawn cannot be distinguished, the author advices to limit the earliest *fajr* time to 30 minutes after the (astronomical) midnight. Likewise, latest *fajr* should be selected as 60 minutes before sunrise (or 150 minutes before noon) [2]. Thus, DTL will be positioned to stay at least 37.5° and at most 172.5° away from the zenith.

Isha starts with the onset of the dusk and continues preferably until the first half or one-third of the canonical night. The latest *isha* cannot surpass ⅓ of the night. Earliest *isha* may be selected as 60 minutes after sunset.

With those measures explained above, 60 minutes at minimum will be available for each of *maghrib*, *isha* and *fajr* prayers. Note that the astronomical midnight, used for polar limitation, is stated as the center of sunset/sunrise; whereas the canonical midnight, used for the end of *isha*, is expressed as the middle of sunset/dawn. Figure 8 visualizes the shortest night (left) and day (right) prayer timings according to this approach. Sunset and sunrise are shown in purple, *fajr* in blue and *isha* in green (⅓ in dotted and ½ in solid) lines.

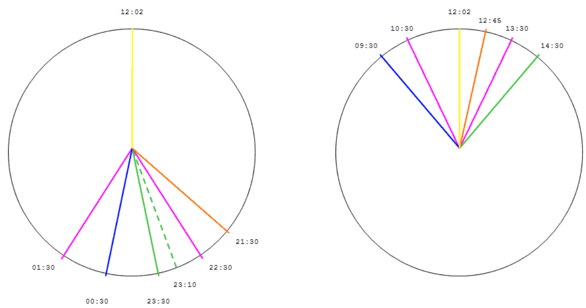

Figure 8 – Prayer Timings for Shortest Night & Day

The effect of confining the prayer timings can be emceed in Figure 5. In the Arctic zone with the shortest night, the width of the olive band (from ⅓ to ½ of the night) is 20 minutes (5° in longitude), such that the total sunset-dawn period will be 2 hours, half of which is the violet region, positioned symmetrically around the lower transit. In the Antarctic area on the other hand, the olive band is 200 minutes wide, the canonical longest night is hence 20 hours long.

4.5 Construction of Calendar

Regional Moonsighting requires the inception of the crescent visibility anywhere on the Earth. Although there are many criteria to define this moment, our recommendation is to require ARCL to reach 8°, as declared in the 1978 Istanbul Conference. This is almost the lower limit of probability (–σ) for naked-eye visibility at 1,000 m altitude, corresponding to the vertex of the orange parabola in Figure 6, where the vertical white bar sits on. The world record for naked-eye observation attained by John Pierce is 8.6°. The algorithm for the computation of the first day of month in an *isha*-based regional lunar calendar can be summarized as follows:

- Let *T* be the local time of either *isha*, or ½, or ⅓ of the night, according to the desired criterion. The first third or half of the night is found by dividing the sunset-dawn interval by 3 or 2, respectively, and then adding this value to the sunset time. Sunset, *isha* and dawn times should be calculated using the polar zone correction method given in the previous section.
- Given a Gregorian date, ARCL at *T* of the previous day is first computed. For a global sighting instead, *T* should be taken as the dawn time of the current day; or rather 00:00 GMT for the single-zone calendar.
- ARCL is then tested against the threshold value of 8°. The Gregorian date is decremented each and the test is repeated as long as ARCL > 8° or the Moon phase angle is greater than 180°. The smallest Gregorian date with ARCL > 8° is then the 1st day of the lunar month.

Note that the lunar date will depend on the location (latitude & longitude) since *T* is the local time, except for the unified calendar.

4.6 Preparation of Regional Map

For demonstration, the *Urcun* software, which was formerly written by the author to visualize the Local Moonsighting by drawing lunar visibility parabolas on an Earth map, is enhanced by the inclusion of regional layout algorithm, as depicted below:

At start, the tool finds the first day of the lunation and calculates the elongation at Greenwich midnight. The initial scan time is adjusted to approx. 2 hours before the first global lunar visibility. The Earth map is scrolled such that the astronomical midnight is centered[5]. It then scans in a loop the initial time of visibility by incrementing the time and testing whether ARCL becomes larger than 8º. At the point of visibility onset, the time and corresponding location (PFV) are displayed.

Normally for every pixel of the map, the conditions should be tested as whether the local *isha*, one-third of the night, the midnight and the dawn has already entered or not. But since this is a very time consuming procedure; the following way is chosen instead:

For every horizontal line (latitude), the related hour angle for sunset is first computed. The associated longitude, after bounding for polar zones, is calculated and then invisibly marked in the map. The adjoined pixels will form STL. The calculations are repeated for *isha*/dawn[6] to build ITL/DTL. The horizontal breadth between STL and DTL is then cut into 2 and 3 to fix the pixels for the ½ and ⅓ of the night, respectively. After the completion of this time loop, the painting routine sweeps the map and changes the color every time a terminator line has been crossed.

Owing to this peculiar algorithm, the multi-color high resolution (1440 x 720) regional sighting map with 5 unique zones can be constructed almost instantly, within 0.2 seconds, including the graphical output.

5. CONCLUSION

In this paper are examined various moonsigthing processes, which are basis for construction of an Islamic calendar. They can be classified in terms of locality as follows:

Locality	Description	Criteria	Border
0	Global (unified)	ARCL > 8º before 00:00 GMT	IDL
1	Wide Regional	ARCL > 8º before local *fajr*	violet red
2	Medium Regional	ARCL > 8º before ½ of local night	olive violet
3	Medium Regional	ARCL > 8º before ⅓ of local night	cyan olive
4	Narrow Regional	ARCL > 8º before local *isha*	gray cyan
5	Local	Extended Crescent Visibility Criterion	orange gray

Category 0 is the absolute global sighting with its single zone which is the whole Earth. It is completely nonlocal because of its independence on the site coordinates. ILML then overlaps with the IDL such that the Hijri date is synchronous with the Gregorian worldwide. Nearly 60% of the globe will be outside of the common night and therefore not comply with religious requirement of fasting time; nevertheless, a large portion of that region is often occupied by oceans and hence not inhabited.

5 *Urcun* produces local and regional maps separately. Figure 5 and Figure 6 are manual combinations of these maps.

6 The Sun depression angles employed in *Urcun* are 1° for sunset and 17.5° for dusk/dawn.

Category 5, on the other hand, has the highest level of locality, because it takes the visibility curve as ILML. There is no common region ever.

Categories from 1 to 4 are based on regional sighting, fully conforming to the common night principle. Category 1, named as Wide Regional, possesses the largest common region up to DTL, but it is inappropriate inasmuch as the visibility commences after the midnight, beyond the (preferential) end of *isha*/*tarawih* prayer period. In contrast, with Category 4, named as "Narrow Regional", *tarawih* can be performed without delay yet it implies a tight space for border adjustment. Remaining categories 2 & 3, grouped under "Medium Regional", are more flexible for political sliding of ILML but *tarawih* needs to be retarded for some time.

The Medium Regional zoning is evaluated as a proper method in establishing a Hijri Calendar because of its advantages such as its conformance to *tarawih* and fasting timings beside its adequate common region for political unity.

In addition to the regional sighting map generator tool integrated into the *Urcun* software, the author has also implemented a Gregorian/Hijri converter for demonstration, with all options of locality, except category 5, as classified in the table above.

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