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Lunar Crescent Visibility Criterion and Islamic Calendar

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SUMMARY

While the Islamic legal system dictates the general considerations for an Islamic time-keeping system, it is science which is called upon to assist in safeguarding these legal precepts. The Islamic lunar calendar is an intensely scientific system, critically involving the astronomy of the new Moon's earliest visibility on local, regional and global scales. During the last 15 years, the astronomical prediction of the new Moon's visibility and its use in a unified International Islamic Calendar has received considerable global attention. Within the religio-legal system, there are important considerations which may help in the simplification of this exercise and which need to be kept in view by scientists. This paper aims to review the developments in the area of a prediction 'criterion' as well as the 'legalistic' aspects underlying this issue. It also highlights how seemingly erroneous reports of Moon sightings complicate the resolution of this issue and the utility of the criterion in discerning the sighting reports. Finally, by re-analysing data it is shown that a composite criterion and a set of derived simplified criteria provide a good starting basis for a unified International Islamic Calendar.

1 INTRODUCTION

In Arabia, use of a lunar calendar is known to have existed from very early times. The names of the months of the old Arabian calendar were the same as those of the present Islamic calendar. The original practice is believed to have been to use '12 lunar months to a year'. On the Pre-Islamic Arab calendar, the annual Pilgrimage (*Hajj*) to *Kaaba* in Mecca was a most significant and important event. This practice is believed to have started with the construction of *Kaaba* by Prophet Abraham and continued in Islam. Although the event of Pilgrimage to *Kaaba* was basically of a religious nature, it was also important for trade and business with a lot of goods exchanging hands. When the *Hajj* was out of season, it created difficulties in procuring the crops and sacrificial animals for trade and use. To overcome this, the Arabs in Mecca are believed to have introduced a system of intercalation known as *Naasi'* in Arabic. A Meccan by the name of 'Qalmas' is reported to be the first person assigned this task (Hashmi 1987) who announced the dates for the coming year's *Hajj* and whether the intercalation was due during each *Hajj* season.

In addition to the month of *Zul Hijjah* (in which the pilgrimage is held), three other months were sacred to the pre-Islamic Arabs. During these months, certain things are forbidden (e.g. wars with opponents etc.). The sacred nature of those 4 months carries on in the present Islamic calendar. In time, the practice of intercalation was much abused (as with the Roman calendar) thus affecting the sacred months and the related prohibitions by changing a sacred month into a non-sacred one.

The calendar in use in Medina (*Medinan*) (North of Mecca) remained in the original '12 months to a year' form. The early Muslims continued to use the Meccan calendar while in Mecca but shifted to the *Medinan* calendar after the Prophet Muhammad (and his companions) migrated to Medina in AD 622. Following the conquest of Mecca in the eighth year of *Hijrah* (AD 629 December), the Muslims continued to use the Medinan calendar but the *Meccan* calendar also ran parallel. However, during the Prophet Muhammad's last pilgrimage in the tenth year of *Hijrah* (AD 632), the much abused Meccan practice of inter-calation was abolished through a '*Quranic*' injunction thus reverting the Arab-Islamic calendar to the simple '12 months to a year' practice. The relevant verses are:

> The number of months
> In the sight of Allah
> Is twelve (in a year)
> So ordained by Him
> The day He created
> The heavens and the earth;
> Of them four are sacred;
> That is the straight usage
>
> (*Qura'n*: 9; 36)

> Verily the transposing
> (of a prohibited month)
> Is an addition to Unbelief:
> The Unbelievers are led
> To wrong thereby: for they make
> It lawful one year,
> And forbidden another year,
> Of months forbidden by Allah
> And make such forbidden ones lawful
>
> (*Qura'n* 9; 37)

The practice of using the newly visible lunar crescent for starting every new month is old and was common with most lunar calendar users as much as those in Arabia. The Islamic calendar also requires the beginning of a month to be based on the first sighting. This was re-emphasized through a Qura'nic verse:

> Concerning the New Moons
> Say: They are but signs
> To mark fixed periods of time
> In (the affairs of) men
> And for Pilgrimage
>
> (*Qura'n*; 2; 189)

This is particularly important for religious events like the beginning and end of the fasting month and the date of Pilgrimage to *Kaaba* in Mecca. This was further emphasized by the Prophet Muhammad in one of his sayings (approximately):

> Begin fast with the sighting of the new Moon and break the last fast with the sighting of new Moon. If it is clouded, complete the month as of 30.

For completeness it is appropriate to include a brief note on the evolution of the Islamic Era (Ahmad 1991). There was no commonly accepted permanent calendar in pre-Islamic Arabia. Nevertheless, the custom of counting years was, in one form or another, prevalent among the Arabs and their neighbours. Opinions are divided as to the origin of this practice. According to Ibn Al-Jazwi, it dates from the time when the children of Prophet Adam multiplied and spread on earth (Rosenthal 1952, p.314, Faruqi 1979, p. 22). In South Arabia, a calendar system originated in BC 115 or BC 109 when the Himyarites adopted one using the reigns of the Tubba as the epoch years of their era. The inhabitants of Sanaa (Yemen) had also adopted a calendar, using the victory over the Yemen by the Abyssinians, and later, the Persian conquest (Rosenthal 1952, p. 314).

The origin of a chronology of events in North Arabia may be traced as far back as to the construction of the *Kaaba* by Prophet Abraham and his son Prophet Ismail. The northern Arabians are also reported to have their famous battle days, such as the war of Al-Bassus, Dahs and al-Ghabra, the day of Dhu Qar, al-Fijar etc. as marking epochs of eras. In Medina also a local calendar is supposed to have existed. Al-Masudi maintains that the people of Medina used the dates of their castles and palaces as their local calendar at the time of the Prophet Muhammad's migration (AD 622) from Mecca to Medina but others reject this, claiming the adoption of an era by the people of Medina to a month or two after the Prophet's arrival, which continued until his death (AD 632). According to a widely held view, the *Hijrah* era was set up at the time of Caliph 'Umar b. Khattab in AD 637/638, i.e. about 5–6 years after the introduction of the purely lunar calendar. After much consultation, the year of Prophet Muhammad's migration (*Hijrah*) from Mecca to Medina was accepted for the beginning of the Islamic (or *Hijrah*) calendar.

The Islamic calendar is both a religious and a civil calendar governing everyday life for the 1 billion members of the Muslim community spread across the world. Examples of areas of interest include: periods of annual month-long fast, pilgrimage, times of marriage and divorce, year of wealth tax for the needy, religious observances and general and historical time-keeping. The crucial role which the phenomenon of 'earliest' visibility of the new Moon plays in this cannot be over emphasized.

2 THE CRUCIAL ROLE OF SCIENCE

The purely lunar calendar was introduced on First *Muharram* 11 AH i.e. 20 days after the *Qura'nic* injunction and later the Islamic *Era* of *Hijrah* was introduced with reference to the event of *Hijrah* (Ilyas 1989a). While *sharia'* (Islamic Legal System) dictates the general considerations for an Islamic time-keeping system, it is science which is called upon to assist in safeguarding these legal precepts.

Based on scientific understanding, certain ground rules are laid down which form part of Islamic Law (*sharia'*) governing the calendar. These include: (1) length of month, 29 or 30 days; (2) length of a year, 354 or 355 days; (3) maximum number of consecutive months, four for 30-day months and three for 29-day months; (4) (a) each new month begins with the first moon light of the new crescent visible on the western horizon after (local) sunset, (b) try sighting the new Moon on 29th day of the month but if it cannot be seen (even because of cloud), complete the month as of 30 days, (c) the visual sighting report must be supported through a witness report, (d) the persons involved in the reporting must be reliable, adult, truthful, sane, with good eye-sight (implied)—punished if proved to be purposely misleading, (e) the visual sighting report should *not conflict* with basic scientific understanding and natural laws: indeed professional scientists' involvement is essential to ascertain the reliability of the reported sighting and the scientific test would include a check on related parameters (e.g. shape of the crescent, position in sky and altitude, time of observation, sky conditions) and (f) sighting must be carried out in an organized way for each and every month.

There is an inherent strength in the Islamic legal system which helps avoid accumulation of an error. *Sharia'* also allows for the correction of a mistake; suppose on the 28th of an Islamic month, the new Moon has been sighted, a correction will be made to the beginning of the month since a month should have 29 or 30 days only. Suppose the month concerned is *Ramadhan* then an extra fast would have to be completed after Eid celebrations!

Clearly, the earliest visibility of the new Moon plays a very critical role in Islamic calendar regulation. The Islamic legal system includes the administration of the Islamic calendar with an appropriate machinery. The Islamic 'State' placed a special emphasis on *Astronomy Research* and it became a standard element in formal religious and legal education. The early Muslim community, based under the clear skies of Arabia and assisted by State-sponsored research, had no serious problem in following these injunctions to regulate their calendar. As the Muslims brought larger domains under their administration so did they bring in cultured civilizations. This together with the State's priority to develop learning and sciences, especially astronomy, contributed enormously to the development of the science of the new Moon's earliest visibility and its advance prediction (criterion) for greatly varying geo-environmental situations. In this, they built upon the work of earlier researchers as well (e.g. Babylonians, Hindus, Jews). Besides rigorous science, simple schemes (zeroth order approximations) were devised to construct long-term calendars especially to inter-convert Islamic dates with Christian and other luni-solar calendrical dates. Based on the technical information, one of the simple schemes (known as schematic or *Istalahi* system) involved a cycle of 30 lunar years in which months approximately alternate with 29 and 30 days and 11 years consist of 355 days, the rest 354.

Backed by extensive researches, Muslim scientists developed visibility tables and produced many reference works. All was well with astronomy and scientific endeavour was at its zenith in the Muslim lands.

Unfortunately, with the 'sack of Baghdad' by Hulagu Khan in AD 1258 and the subsequent demise of scientific scholarship and a gradual decline in technical expertise in astronomy in the Muslim lands, the use of proper 'expected visibility' rules (devised by the Muslims during 700 years of research) for the construction/verification of local calendars became too complicated for the later Muslim calendar makers. Some of the communities adhered to the direct sighting practice, while others turned to simpler or approximate considerations associated with the lunar conjunction. In some cases, it was assumed that if conjunction took place before sunset, the Moon being above the horizon at sunset, a new Islamic month could be begun. Some assumed (wrongly) that the Moon just above the horizon should become visible as the Sun and other stars do (e.g. see Taib 1978, Ilyas 1978a) overlooking the fact that the Moon (like the planets) has no light of its own and can be sighted (become visible) only through reflected sunlight.

It has therefore become even more important today than ever before to develop a lunar visibility criterion and apply it to establish global visibility of the new Moon. Indeed, only during the last two decades has this issue received serious attention as detailed in this paper.

3 CRITERION FOR THE NEW MOON'S EARLIEST VISIBILITY: HISTORICAL PERSPECTIVE

The geometrical configuration of earth (observer), Moon and Sun and the relevant arcs and angles are shown in Fig. 1. Those of specific interest include: arc of light or elongation (a_L), arc of separation (a_s), arc of descent (a_D), altitude angle (A), azimuth angle (Az), zenith angle (Z).

The scientific interest in predicting the time of the earliest possible new Moon sighting (for a clear sky) goes back to a period at least as early as the Babylonian era. Based on careful observational data, a simple criterion was developed and passed on to the Muslims through Hindus, apparently with very little further improvement. This problem was thoroughly investigated by the early Muslim astronomers in the 8th-to-10th century AD and included such notable persons as Habash and Al-Battani.

The physics-based system(s) for the criterion, developed up to the 11th century (AD) saw very little further developments until Bruin (1977) developed a modern version of the earlier system. On the observational side, after the Ancients' criterion, only in the early 20th century did Fotheringham (1910a, b) and Maunder (1911) develop observational criteria based on new data taken at Athens. In the last 15 years, under an organized programme, progress has been made towards overcoming some inconsistency between the Maunder and Bruin criteria leading to a composite criterion suitable for global applications and the development of First (expected) Visibility based (global) International Lunar Date Lines (ILDL). We qualitatively summarize the development of various criteria through the last *5000 years* or so.

3.1 *Babylonian Criterion*

The earliest astronomical criterion for ascertaining the lunar crescent's first visibility was established in the Babylonian era. Based on observational data, and widely used by early astronomers, this criterion (Fig. 2) is more a rule of thumb which may be stated as follows.

(1) At local sunset, the Moon's age must be more than 24 h, i.e. from the time of conjunction (Moon, Sun) to the time of evening of observation.

(2) $a_s > 12°$ i.e. Moonset is about 48 min after sunset.

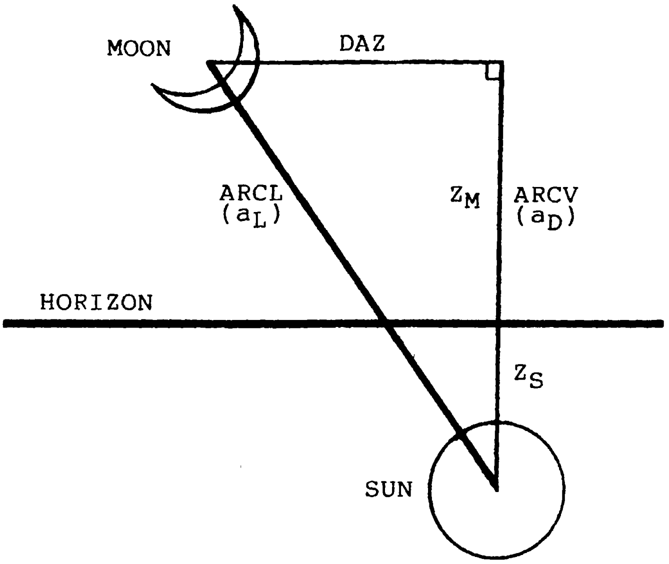

FIG. 1. Position of the Moon after sunset with various celestial arcs: ARCL (arc of light), a_L, is ecliptic longitude separation between Moon and Sun ($\lambda m - \lambda s$); ARCV (arc of vision or arc of descent), a_D, is Moon's altitude separation from the Sun ($h+s$ or ΔA); DAZ, ΔAz, is azimuth separation of the Moon from Sun; arc of separation, a_S, is equatorial separation in right ascension for Moon and Sun ($\alpha_m - \alpha_s$) and is related to a_D and ϕ (latitude of observation place) by $a_D = a_S \cos \phi$.

3.2 *Hindus (AD 500–700)*

Although, for practical purposes, the Babylonian criterion is relatively simple, it remained unchanged until recent times. Nevertheless, in the earliest Hindu texts (*Panch Sidhantika*, AD 500) one finds mention of the fact that the lunar crescent's width is also an important variable in determining the conditions of visibility (Bruin 1977, p. 337). It must also be realized that although an observationally developed criterion was obtained quite early, an elaborate system of calculation was not well developed until the time of early Hindu texts, *Sidhantas* (AD 500). Then, according to Bruin, at various places in the early Islamic literature, one finds mention of the conditions under which the new crescent may be seen (Fig. 3).

3.3 *Muslim Astronomers (AD 700–1100)*

Yaqub Ibn Tariq, one of the earliest Muslim astronomers had developed tables for ascertaining the lunar crescent's visibility (Kennedy 1968) and is reported to have recognized the importance of the crescent's width (Bruin 1977). Various Arab astronomers have given rules that indicate a weighting given to the widening crescent, values of a_S varying between 12° (narrow crescent) and 10° (wide crescent) (Fig. 3). Among the best known early astronomers on the subject are Habash, Al-Khwarizmi, Al-Farghani and Al-Battani from the Abbasid court of Al-Mamun in Baghdad. They made calculations of the crescent's visibility which is considered to have been a formidable problem then, involving every aspect of mathematical astronomy (Bruin, p. 335). For example, Al-Khwarizmi gave mathematical rules and tables for predicting the new crescent and Al-Battani gave a complete solution and was followed by later astronomers such as Ibn Maimon and

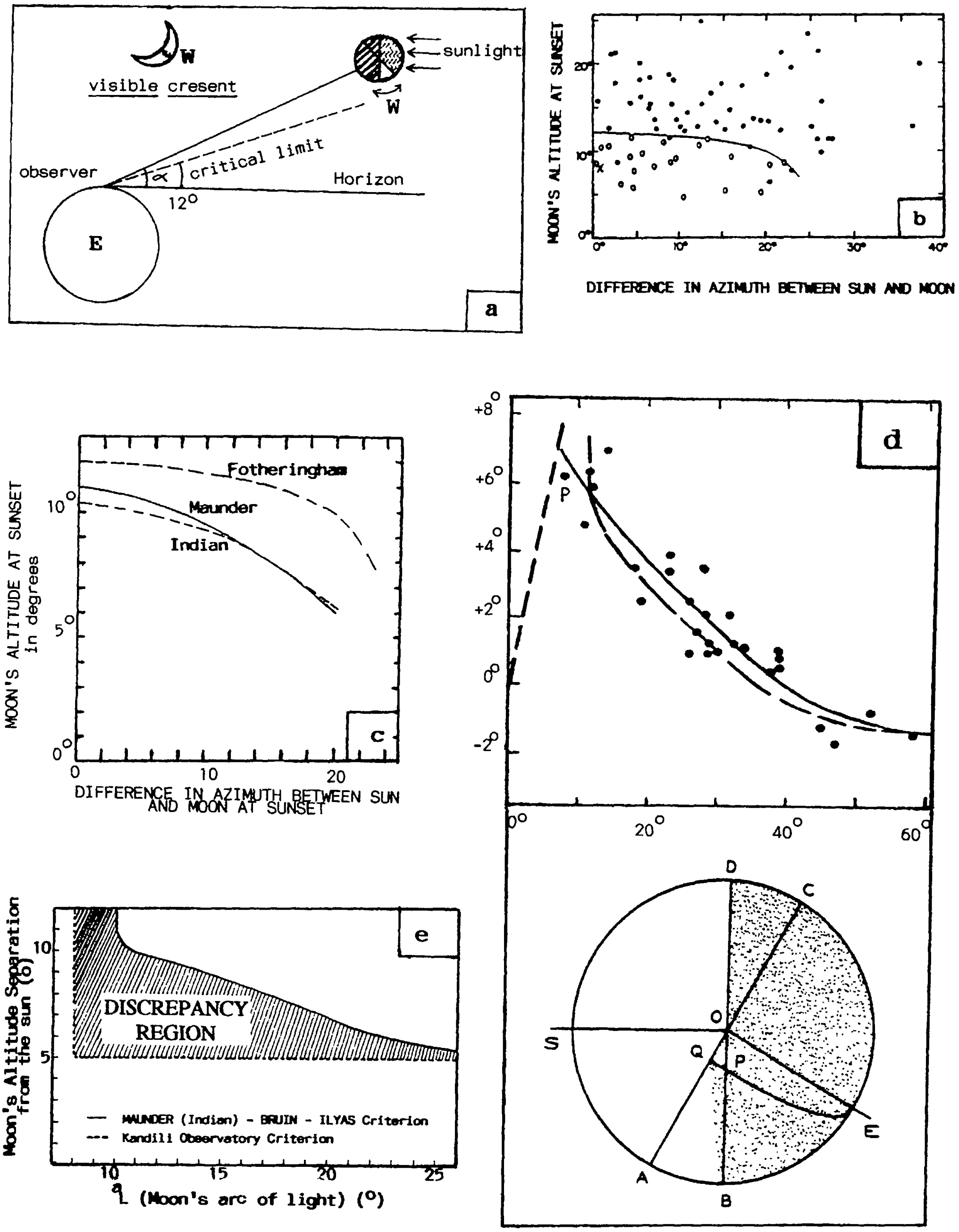

FIG. 2. Examples showing the evolution of 'observational' criterion: (a) Ancients, BC 1000: the 12° marked on the Fig. refers to the a value adopted as a standard for criterion of earliest visibility; (b) Fotheringham, 1910; (c) Maunder & Indian (Schoch) modifications, 1911/1960; (d) Danjon (1932) and Ilyas (1983) and Danjon Limit's geometrical configuration; (e) Istanbul/Danjon (1978).

others. A century later, Al-Biruni in his *Chronology* is reported to have recommended Battani (Bruin, p. 335):

> The computation of the appearance of the new crescent is a very long and difficult procedure, the demonstration of which requires long calculations and many tables. What is needed for this, one can read in the Handbook of Astronomy written by Muhammad Ibn Gabir Al-Battani, or in one of the works written by the mathematician Habash.

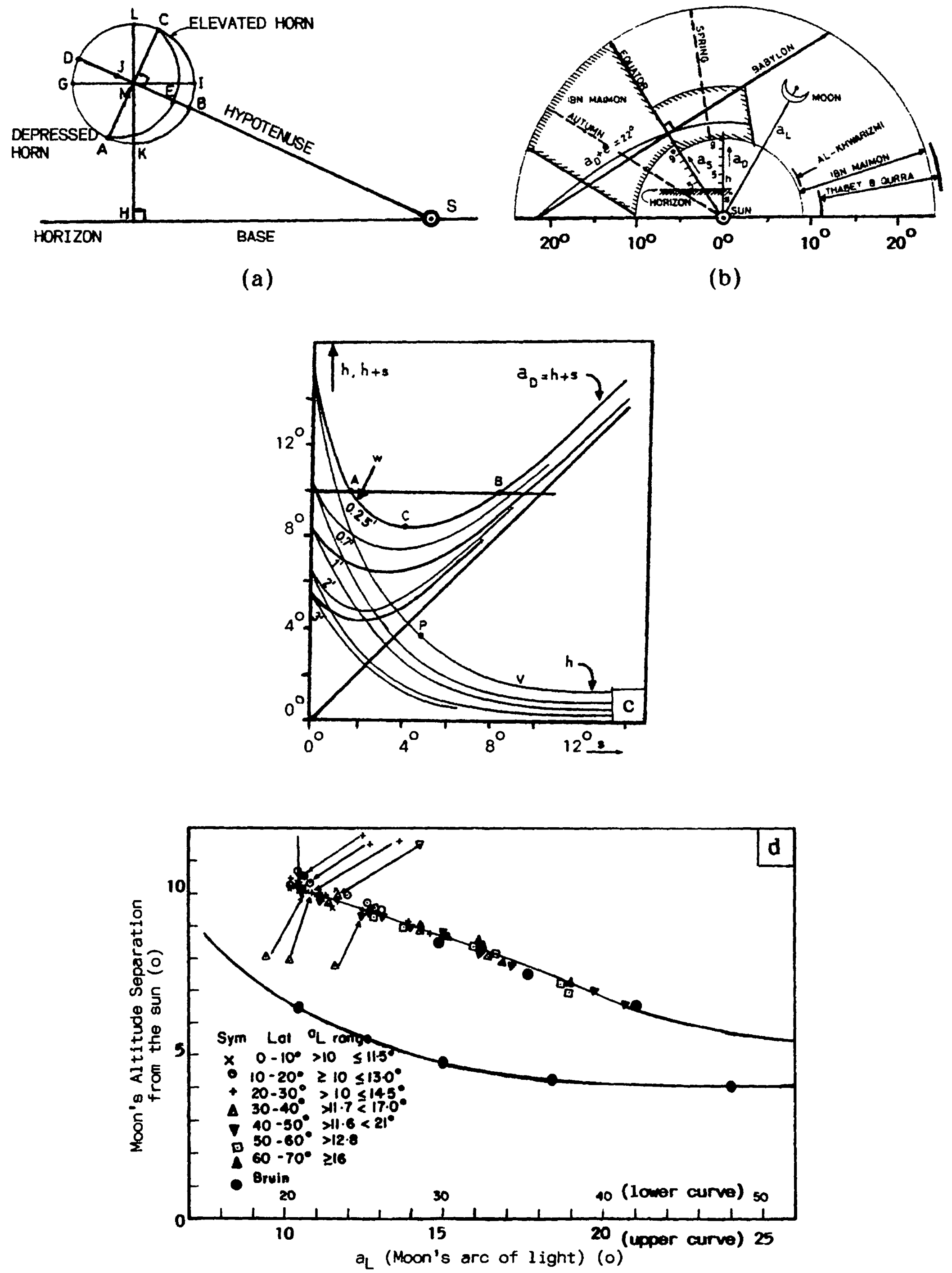

FIG. 3. Examples showing the evolution of 'theoretical' criterion: (a) Hindus, AD 500; (b) Muslims, AD 800–1500; (c) Bruin (1977); (d) Ilyas (Bruin/Fotheringham composite; 1981).

Al-Battani's *Handbook of Astronomy* was edited in 1903 by C.Nallino together with a Latin translation and commentary. Bruin (1977) has made an English translation from Arabic of the 41st chapter of the *Handbook* which deals with the new Moon. Al-Battani knew that the more than 24-hr age criterion (or arc of separation of 12°) is a good starting point but that it is an approximation and that the Ancients did not understand the phenomenon

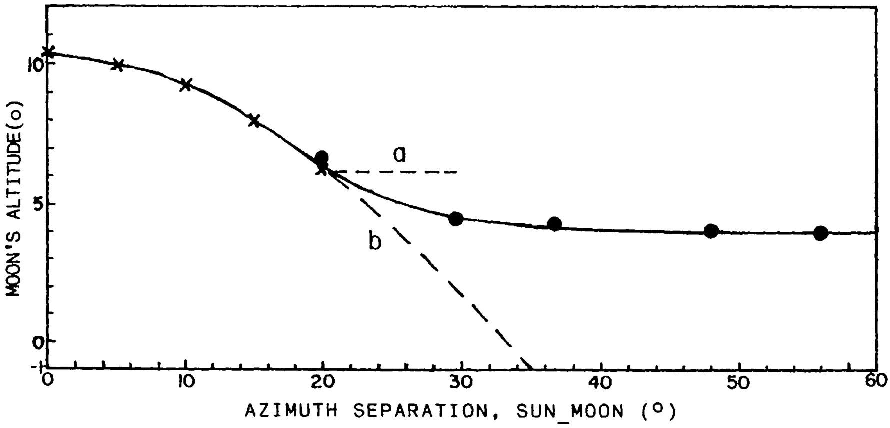

Fig. 4. The extension of the Maunder-Fotheringham (Indian version) 'azimuth-altitude' criterion to large elongations: x: criterion available prior to Ilyas's extension, ●: extension by Ilyas (1988) using 'altitude-arc of light' criterion. Curves a and b are two possible extrapolations proposed for use at large elongations prior to Ilyas' extension (see Ilyas 1984). That these extrapolations, based on simple considerations, are unsuitable is clearly evident.

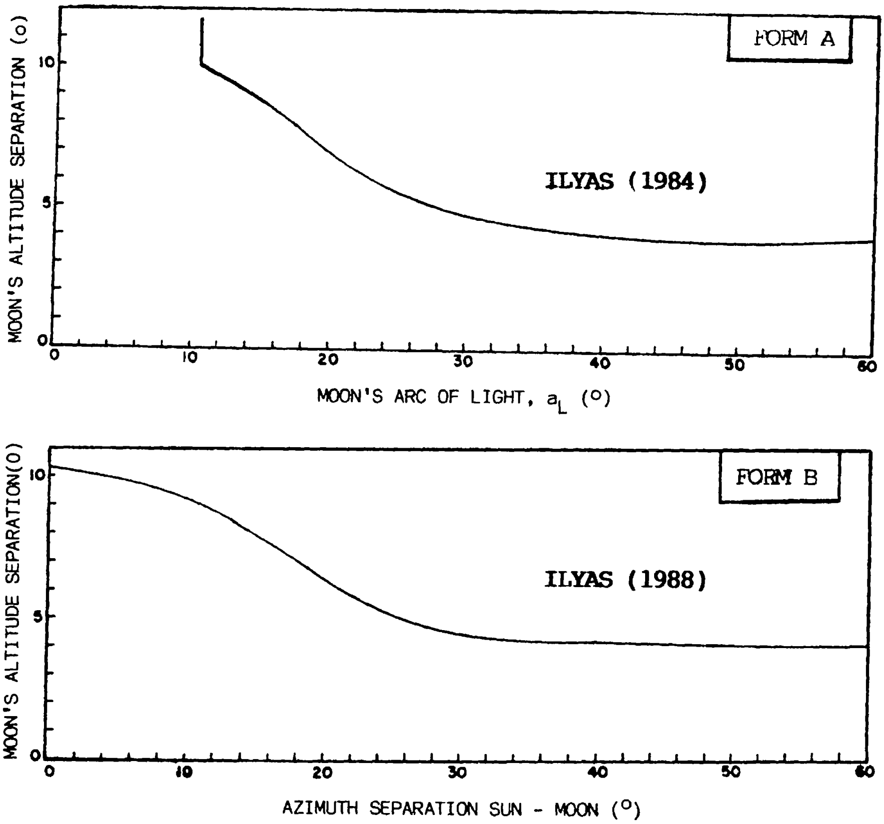

Fig. 5. Composite extended modern criterion (Ilyas 1988).

completely but only approximately (Bruin, p. 346). Further, he states that for various reasons, the crescent will not appear according to one single 'arc' but to many different 'arcs' and then goes on to the details of computation involving several variables and corrections including the effect of Earth-Moon distance, shape (and width) of the crescent, etc; it is a very elaborate mathematical calculation system.

TABLE I

Global Visibility Data

A sample of global visibility data on ILDL (from 30-year data set given in Ilyas (1984a). The table lists earliest visibility longitudes (λo) meeting the minimum visibility criterion at local sunset at different latitudes for each lunation (see Fig. 7a). These λo values with corresponding latitudes can be plotted on a geographic map to produce an International Lunar Date Line (ILDL) as illustrated in Fig. 7b.

			Local date		Latitude												
					N						S						
Ser no.	Lunation	Conjunction (universal date)	Year	Day no.	60	50	40	30	20	10	0	−10	−20	−30	−40	−50	−60
297	990	2.86	2003	3	20 E +	165 E +	110 W	55 W	10 W	20 E	40 E	50 E	55 E	45 E	25 E	15 W	110 W
298	991	32.46	—	33	75 W	15 E	75 E	120 E	155 E	175 E	170 W **	160 W **	160 W **	170 W **	160 E	95 E	30 W
299	992	62.10	—	62	120 E +	180 W	140 W	105 W	80 W	65 W	60 W	60 W	65 W	85 W	140 W	135 E +	25 W +
300	993	91.80	—	92	105 W	65 W	30 W	10 W	5 E	15 E	15 E	5 E	20 W	65 W	135 W	105 E +	145 E +
301	994	121.52	—	122	10 E	50 E	75 E	90 E	95 E	95 E	85 E	65 E	30 E	30 W	120 W	105 E +	155 W +
302	995	151.21	—	152	125 E	180 W **	150 W **	140 W **	135 W **	140 W **	155 W **	180 W **	140 E	85 E	0 E	130 W	75 E
303	996	180.81	—	181	105 W	10 W	30 E	45 E	50 E	40 E	25 E	5 E	30 W	75 W	140 W	125 E +	60 W +
304	997	210.31	—	211	60 E	175 E	130 W **	105 W **	100 W **	105 W **	115 W **	130 W **	155 W **	170 E	125 E	60 E	30 W
305	998	239.74	—	240	160 W	25 W	45 E	85 E	105 E	110 E	110 E	100 E	85 E	60 E	30 E	10 W	65 W

306	999	269.13	—	269	140 W +	105 E +	160 W	105 W	70 W	50 W	45 W	45 W	50 W	60 W	80 W	105 W	135 W
307	1000	298.55	—	299	180 E +	120 W	10 W	60 E	105 E	135 E	155 E	165 E	165 E	165 E	155 E	135 E	110 E
308	1001	327.98	—	328	175 W +	65 E +	175 E +	110 W	60 W	25 W	0 E	15 E	20 E	20 E	20 E	0E	30 W
309	1002	357.43	—	358	105 E +	45 W	50 E	110 E	155 E	170 W **	150 W **	135 W **	125 W **	125 W **	130 W **	155 W **	135 E
310	1003	21.91	2004	22	130 E +	135 W	65 W	25 W	10 E	40 E	55 E	65 E	70 E	65 E	45 E	0 E	110 W
311	1004	51.41	—	52	45 E	100 E	145 E	175 E	165 W **	150 W **	140 W **	140 W **	145 W **	165 W **	150 E	75 E	75 W
312	1005	80.95	—	81	115 W	75 W	50 W	30 W	20 W	15 W	20 W	30 W	55 W	100 W	170 W	75 E +	180 W +
313	1006	110.55	—	111	45 E	75 E	90 E	100 E	105 E	95 E	80 E	55 E	15 E	50 W	145 W	70 E +	180 E +

Symbols: E, east longitude; W, west longitude; +, next date to that listed in column 3; and **, previous date to that listed in column 3.

3.4 *Stagnation in the Progress of the Criterion* (*AD 1100–1800*)

Despite the elaborate system developed by Al-Battani and others, it appears that, in the later period, primarily the Babylonian criterion remained in use since later astronomers such as Al-Sufi (in the same 10th century) and Al-Kashani (in the 15th century) both quote $a_S > 12°$ criterion in their books *Astroglobes* and *Khaqani Zij* respectively. In the following centuries, with the gradual political decline of the Islamic Empire, the system(s), even the simple—but relatively accurate for the tropics—Babylonian rule, appears to have gone out of wide Muslim usage and then forgotten. No further developments anywhere appear to have taken place in this area of science until the second half of the 19th century.

3.5 *New Observational Criterion* (*AD 1860–1975*)

In the later half of 19th century, Schmidt at Athens made careful observations of more than 6 dozen youngest crescents over a period of around 20 years and recorded the relevant data (Schmidt 1868, Mommsen 1883). Fotheringham (1910a, b) used the data for developing an '*Altitude-Azimuth*' criterion. It was revised by Maunder (1911) after adding some more observations with an Indian Astronomical Ephemeris version (by Carl Schoch) (e.g. IAE 1979). A similar criterion has been associated with Al-Biruni with a claim that Fotheringham only rediscovered it (Rizvi 1974). In any case, it represented the first significant development since Al-Battani's period. The criterion, even though based on a rather small data set, confined mainly to Athens, is comprehensive yet very simple for global applications (Ilyas 1979). However, it appears that the Muslim scientists continued to overlook the earlier criteria well into the 1970s. No explicit popular usage of an established criterion is known to have taken place in the Islamic world. It is noteworthy that the *Indian Astronomical Ephemeris* is the only Almanac which has been listing some of the first Islamic calendrical dates for some years according to the *Schoch criterion* but only with reference to a local meridian.

3.6 *Modern Developments*

Bruin (1977) presented an independent first-visibility criterion based on elaborate theoretical considerations (similar to those by Al-Battani and others in the medieval period) and involving such variables as the evening sky's brightness, discernible contrast, crescent's intensity, etc. The system is considered quite accurate and also enables one to determine the duration of visibility at a given place. A test of internal consistency between Bruin's theoretical criterion and Maunder's observational criterion was desirable. Initially, a large discrepancy was encountered. However, through a slight modification this discrepancy could be resolved with a downward modification of the lower limit of observable lunar width in the 'Bruin-criterion' (Ilyas 1981). This has resulted in a much greater confidence in Maunder's observational criterion and one may use the criterion in the 'Maunder' or inverted 'Ilyas' form for global applications (Ilyas 1982a) (Fig. 5). There is an increased confidence in the criterion due to the fact that simpler 'latitude

TABLE II

Monthly data

A sample of monthly data on Islamic dates included in the regional calendars (Ilyas 1994). The table also includes newly introduced universal reference parameters including Islamic Lunation Number, Hijrah Day Number and Islamic Day Number as well as the conventional Julian Day Number.

Lunar cycle	*Lunar Conjunction*
Islamic lunation number: 17018	Julian Day: 2450910.08
Astronomical Lunation Number: 933	Solar Day: 1998 Apr 26: 1142 (UT)**

First Evening Visibility Of The New Moon: 1998 Mon 27 April

Hijrah Day	Islamic (Lunar) Date*				Gregorian (Solar) Date*				Julian Day
490000++	Year	Day#	WkDay	Date	Year	Day#	WkDay	Date	2440000++
12491	1419	1	Tue	1 Muharram	1998	117	Mon+	27+ Apr	10930.5
12492		2	Wed	2		118	Tue+	28+	10931.5
12493		3	Thu	3		119	Wed+	29+	10932.5
12494		4	Fri	4		120	Thu+	30+	10933.5
12495	1419	5	Sat	5 Muharram	1998	121	Fri+	1+ May	10934.5
12496		6	Sun	6		122	Sat+	2+	10935.5
12497		7	Mon	7		123	Sun+	3+	10936.5
12498		8	Tue	8		124	Mon+	4+	10937.5
12499		9	Wed	9		125	Tue+	5+	10938.5
12500		10	Thu	10		126	Wed+	6+	10939.5
12501		11	Fri	11		127	Thu+	7+	10940.5
12502		12	Sat	12		128	Fri+	8+	10941.5
12503		13	Sun	13		129	Sat+	9+	10942.5
12504		14	Mon	14		130	Sun+	10+	10943.5
12505		15	Tue	15		131	Mon+	11+	10944.5
12506		16	Wed	16		132	Tue+	12+	10945.5
12507		17	Thu	17		133	Wed+	13+	10946.5
12508		18	Fri	18		134	Thu+	14+	10947.5
12509		19	Sat	19		135	Fri+	15+	10948.5
12510		20	Sun	20		136	Sat+	16+	10949.5
12511		21	Mon	21		137	Sun+	17+	10950.5
12512		22	Tue	22		138	Mon+	18+	10951.5
12513		23	Wed	23		139	Tue+	19+	10952.5
12514		24	Thu	24		140	Wed+	20+	10953.5
12515		25	Fri	25		141	Thu+	21+	10954.5
12516		26	Sat	26		142	Fri+	22+	10955.5
12517		27	Sun	27		143	Sat+	23+	10956.5
12518		28	Mon	28		144	Sun+	24+	10957.5
12519		29	Tue	29		145	Mon+	25+	10958.5

* The Islamic day and date begin at the sunset on the Gregorian day and date shown. The '+' sign signifies that it ends on the next sunset.

++ Add the number at the head of the column to the number in the column.

** UT (Universal time) + ZT (Zone Time) = LST (local standard time).

dependent' *Moon's age* (Fig. 6a) and *Moonset-lag* (Fig. 6b) criteria derived from this system are found to be consistent with earlier work (Ilyas 1983a, b, 1985, 1987). Recently, Ilyas (1988) has further improved the composite criterion (Fig. 4) as discussed below.

Given a reliable criterion, we can develop an extensive global computational system for locating the geographical longitudes at each latitude where the minimum (visibility) condition is just met (Ilyas 1982) (Fig. 7a). A curve

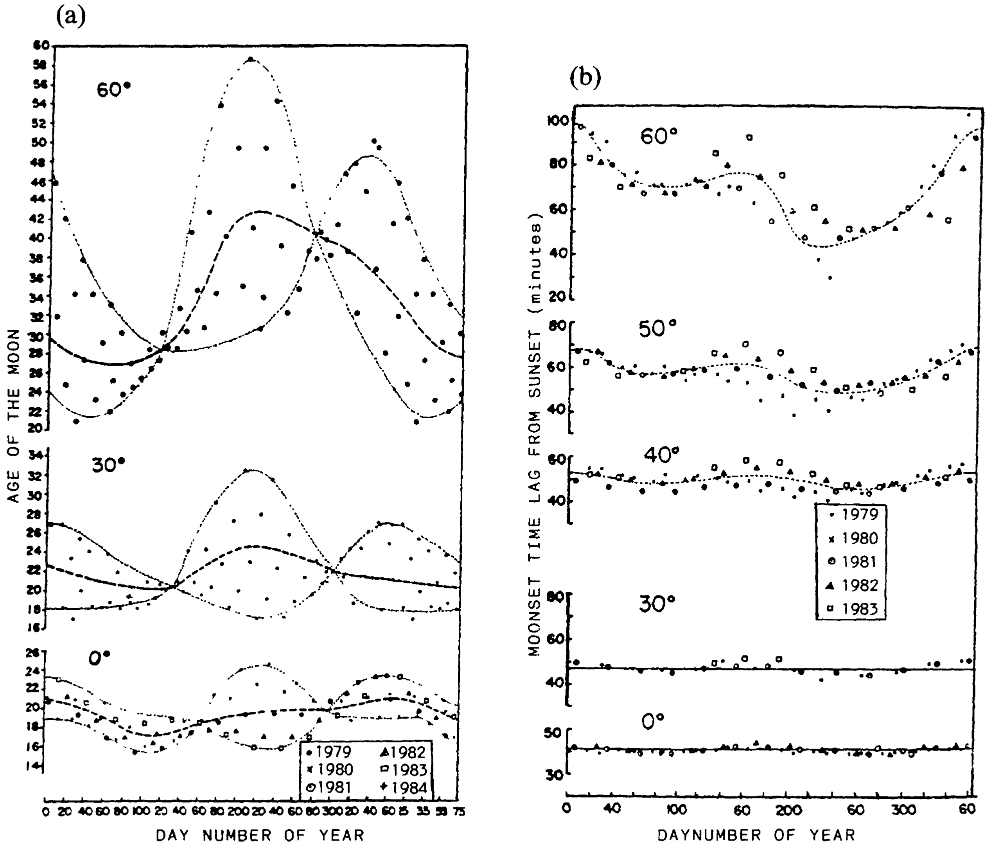

FIG. 6(a). Latitude-season dependent simplified 'Moon's Age' criterion derived (I Level) from the composite criterion shown in Fig. 5 (Ilyas, 1983). (b). Latitude-season dependent simplified 'moonset-lag' criterion derived (II Level) from the composite criterion shown in Fig. 5 (Ilyas 1984).

(line) drawn through these points would result in what we may refer to as an *International Lunar Date Line* (ILDL) similar to the (International) *Solar Date Line* (Fig. 7b). After the development of a comprehensive computational system (Ilyas 1984b), a multipronged application-oriented effort has been initiated aiming at the correction of the systems in use and further improvements to the present system, to whatever extent possible. This effort has included a provision for the supply of the yearly astronomical data on (expected) earliest lunar visibility, worldwide, during the 1979–84 period (after this, the 30-year global data were published (Ilyas 1984b) and also provided through a series of 5-year and 15-year regional calendars). A sample is given in Tables I and II (Ilyas 1991).

4 MODERN CRITERIA FOR THE NEW MOON'S EARLIEST VISIBILITY

The *first* (*earliest*) *visibility* of the new Moon has been the basis of lunar calendars from the earliest times (Babylonians, Greeks, Maya, Inca, Chinese, Hindus, Jews; Muslims) and scientists have been interested in developing an astronomical criterion. Very early, it was recognized that after lunar conjunction (with the Sun), the new Moon needs to grow to some extent before the crescent can be seen. This minimum requirement for earliest visibility has been represented in simpler astronomical terms such as *Moonset*

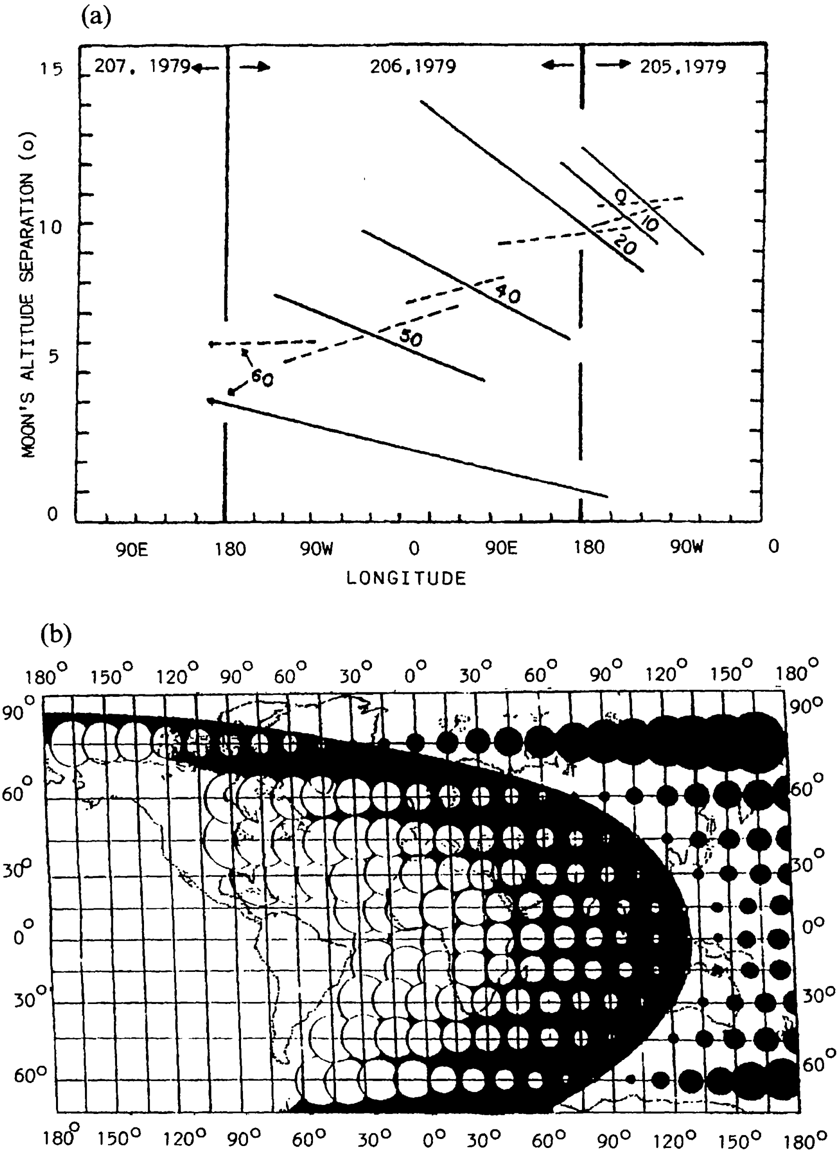

FIG. 7(a). The unbroken lines represent the variation of the Moon's altitude separation from the Sun at the time of local sunset as a function of terrestrial longitude for several N latitudes marked at the intersection (0, 10,..., 60). The numbers 205, 206 and 207 refer to the solar day numbers in 1979. The broken lines indicate the values of minimum altitude separation required according to the visibility criterion corresponding to the lunar azimuthal separation from the Sun (at local sunset) at each location. For each latitude, the longitude where the minimum visibility conditions are met is given by the intersection of the two curves. These longitude-latitude combinations are then used to form a geographical boundary meeting minimum visibility conditions and referred to as an International Lunar Date Line (ILDL) as shown in b. (b). Schematically illustrates how along the latitude circles, the probability of visibility decreases to the east of ILDL (growing dark circles) and increases to the west of ILDL (growing white circles).

lag from sunset or *Moon's age at sunset*. In comprehensive forms, the criteria relate the relative positional parameters of the Sun and the Moon (with reference to an observer) to the optical observational requirements for the human eye. The latter involve considerations such as the light intensity of the illuminated fraction of the lunar surface facing the observer, brightness of the evening sky, contrast requirements of the eye, atmospheric refraction, etc.

In the actual development of the criterion one may take either of the following two approaches.

(1) In the observational approach, one needs to obtain data on the crescent's visibility in the form of positive and negative sightings and parametrize these in astronomical terms. The earliest simple Babylonian criterion was obtained in this way and so was the comprehensive Maunder/Fotheringham criterion of 1911/1910.

Obviously, this process requires a long observational period and wide global coverage for greater accuracy. Observations, however, help in identifying new features such as the limb shortening, Danjon Limit and related aspects—seeing, extinction and limb shadowing (see the discussion later). A summary of progressive stages of observational criteria is given in Fig. 2 and some of these are discussed further in the following discussion.

(2) In the theoretical approach, the optical parameters—sky brightness, crescent's intensity, contrast, etc.—are parametrized in the Sun–Moon positions and physical requirements. The medieval work of the Muslims was of this type and the recent work of Bruin is an improved version of this approach. The method is somewhat complex but, in principle, more accurate and universal. A summary of various key developments is given in Fig. 3.

In the following pages, a brief discussion of the four primary types of modern criteria is given, reflecting the current state in this area.

4.1 *Observational* ΔA, ΔA_z

In order to develop a simplified criterion, Fotheringham, in 1910, made a collection of 76 naked eye observations of the visibility or non-visibility of the crescent in the years 1859 to 1880, mainly using Schmidt's log at Athens (Schmidt 1868) and similar data by Mommsen (1883). For each observation, the altitude (or zenithal separation) of the Moon and its azimuthal separation from the Sun at local sunset time were calculated and a plot of the parameters was made for the data set. Fotheringham identified the visibility data from the non-visibility data and observed that a clear dividing line (curve) could be drawn between the positive and negative observations; the positive ones lying above the curve (Fig. 2b). Later, Maunder added a few more observations and drew the curve somewhat lower arguing that the observations in which the crescent was not seen were more liable to be mistaken i.e. in comparison to positive observations. This view is shared by Ashbrook (1971) who points out that Schmidt's log of his observations indicates that he seldom saw any extremely young crescent; the Indian Astronomical Ephemeris (e.g. IAE, 1979) lists a slightly modified version of this criterion by Carl Schoch (W.G.Waddington, private communication). The three versions are shown in Fig. 2(c). As noted elsewhere, Rizvi has claimed that the *altitude-azimuth* separation criterion of Fotheringham was originally proposed by the great Muslim scientist and astronomer, Al-Biruni (10th century AD) and was then rediscovered by Fotheringham. Fotheringham, in his paper, mentions a similar criterion (in elongation and angle of vision—perhaps zenith distance) given by Maimonides which results in slightly lower values but what influence Al-Biruni's work had on Fotheringham's criterion would need to be closely investigated.

From the curves in Fig. (2c), we note that the required altitude of the Moon from the setting Sun can be smaller for a greater azimuthal separation but with a limiting value of about 6° (it is now considered necessary to modify this figure for the larger elongations normally encountered at high latitudes as discussed later on). This means that at a given location the very young Moon would not be visible by just being above the local horizon (as in the case of the Sun) but would have to be considerably above the horizon to become *just visible*; this fact, as pointed out earlier (Ilyas 1978a, b), if not realized, may lead to erroneous judgements (Taib 1978). Some explanation for this is given by Danjon (1932) relating it to the mountains on the lunar surface which he suggested tend to shadow part of the sunlit surface. We shall examine this matter more closely towards the end of this section.

The empirical relationship of Fotheringham (and later versions) takes into account only the relative positions of the Sun, Moon and horizon. Fotheringham claimed that the criterion is independent of differences in latitude 'subject to a slight modification for permanent differences in the clearness of the air'. Because the criterion was developed using the data taken mainly at Athens (38° N), Reynold (1939) has suggested some latitude dependence in the criterion, thinking it to be invalid at latitudes above 50°. However, from an inter-comparison of this criterion with an independent theoretical criterion (Ilyas 1981), the internal consistency shows it to be generally valid for all latitudes but needing some revision to extend the criterion to larger elongation angles (see the discussion below).

4.2 *Theoretical* ΔA, a_L *Criterion*

As summarized earlier, the physics-based theoretical criterion was developed by the Hindus and astronomers like Al-Khwarizmi (Suter 1914), Al-Battani (1903), Ibn Maimoon (Neugebauer 1949; Gandz 1956), Al-Biruni (1879). Bruin used recent data on factors like the illumination of the evening sky, light intensity of the crescent as a function of its width and solar depression, and necessary contrast for unaided human eye, etc. The criterion is presented in the form of curves of lunar altitude separation, a_D $(h+s)$ from the Sun as a function of solar depression (s) near sunset for various values of the crescent's width, w up to 0·5′ (or arc of light, a_L) (Fig. 3c).

Ilyas (1981) showed that Bruin's criterion extended to $w = 0{\cdot}25'$ is in excellent agreement with the Maunder (Schoch) criterion. Since the former is of a precise nature and independent of latitude, the latter may also be assumed to be so. The lowest limit for $a_L \sim 10{\cdot}5°$ ($w \sim 0{\cdot}25'$) may in fact be deduced directly from the Maunder limit (Ilyas 1983b). In view of the internal consistency between the two criteria, we may treat the 'ΔA, ΔA_Z' and 'ΔA, a_L' criteria as two forms of the composite theoretical-observational criterion (Fig. 5). A series of additional considerations have now been made as discussed below.

The Lowest Limit in a_L *and the Danjon Limit.* The elongation or *arc of light* a_L, is related to the *crescent width* w and thus to the observable intensity of the crescent. The limiting value of elongation (or w) for the youngest observable crescent (Bruin 1977), also known as the Danjon Limit after Danjon (Danjon 1932, Ashbrook 1972) who first tried to study the physical cause for this, is of direct interest. Useful as a rule of thumb, the Danjon Limit can be mistakenly used as a stringent basis for calendrical work (Calendar Commission 1978), giving rise to conflicting results and the need for a close examination of its predictive use (Ilyas 1983b). We devote some space to this matter.

Danjon is reported to have noticed the phenomenon of the crescent's limb shortening (less than a half circle of the crescent) for a young Moon in 1931 which he later discovered to be a general phenomenon as being due to the shadowing effect of lunar mountains at small elongations (Danjon 1932, 1936, Ashbrook 1972). Danjon deduced the magnitude of this crescent shortening in the form of a deficiency arc as a function of elongation. For this he employed measurements of estimated crescent length and by extrapolation deduced the limiting elongation to be about 7°. However, a re-examination of Danjon's data (Ilyas 1983b) leads this limit to be about 10° rather than 7° (Fig. 2d) which is consistent with the a_L limit (10·5°) derived using the visibility criterion.

The revised limit is consistent with the general ruling from the Royal Greenwich Observatory (RGO 1979, Ilyas *et al.* 1979): "it is unlikely that the new crescent will be visible unless the elongation exceeds 10° and the altitude of the moon exceeds 5° when the depression of the Sun is 3°". We will further notice that the composite criterion with the revised lowest limit leads to consistent 'age' and 'moonset lag' criteria. Nevertheless, we must recognize that what Danjon had proposed, as a general guide, was an approximate minimum elongation necessary for the young observable Moon. The 'limit' is not a sufficient condition and even the revised Danjon Limit, alone, cannot be used as a basis for visibility prediction. This critical difference was overlooked at the 1978 Istanbul conference which adopted a similar ($a_L = 8°$, $\Delta A = 5°$) criterion by joining, rather arbitrarily, the old Danjon Limit with a 5° altitude separation (Dizer 1980, personal communication) as discussed elsewhere (Ilyas 1981, 1982). Its effect on the predicted data, especially in the tropical region, would become more serious due to the under-estimation in the limiting value (Ilyas 1982b).

Using a set of about 75 observations, Danjon established a relationship between the amount of limb shortening (or arc of deficiency), the elongation (a_L), and the length of lunar crescent ($2w$; $2w = 180°$ for smooth sphere) by:

$$\sin \alpha = \sin a_L \cos (w). \qquad (1)$$

Danjon (1932) explained this in a diagram shown in Fig. 2(d) where we have the Moon represented by ABCD. SO represents the direction of sunlight which illuminates front hemisphere (BSD). OE represents the earth-bound observer having the hemisphere AED in view which includes the lighted segment of the surface AOB appearing as a crescent of width AB. Danjon argued that at small elongations (less than 40°), the observable cusp at O shifts downward to Q, thus reducing the half-length of the crescent to AQ(w) which is related to the deficiency arc QP(α) as shown above. The triangle OQP becomes invisible. Danjon found that at a critical limit of around 7° (really ~ 10°—see Ilyas 1983b), the arc QP becomes equal to AB and thus there no longer remains any sunlit crescent visible. (At elongations greater than 40°, α becomes negative—hence an increase in sunlit surface!).

The observed phenomenon of limb shortening is real. There are, however, several views about what might be causing this phenomenon (Ilyas 1984a). The widely known explanation is the one given by Danjon (1932) himself. He explained this to be the result of the lunar mountains' shadowing effect as represented by the shading all the way to AB (Fig. 2d). When I began to examine the lunar crescent visibility criterion in the early 80s, I raised this issue with McNally (1983), who, after considering the non-sphericity of the moon's figure, concluded that 'atmospheric seeing' (or non-steadiness) was the dominant factor responsible for the limb shortening. Other factors such as atmospheric clarity and contrast with background sky etc., could augment the magnitude of this effect. In a recent review, Schaefer (1991) has argued that 'atmospheric seeing' could not cause the limb shortening significantly. Instead, he has proposed that the phenomenon is simply due to the falling-off of crescent brightness at the cusps below the eye's threshold limit for detectability. According to this explanation, as one approaches the Danjon Limit (limiting elongation $\sim 10{\cdot}5°$ or $w = 0{\cdot}25'$), the entire crescent brightness would be below the human eye's detectability and nothing will be seen. Telescopic aid would have but marginal effect since low magnification instruments would not help improve the surface brightness density or contrast against the sky brightness. Improved acuity of the human eye would of course help as would be the case with better atmospheric conditions.

Although, at smaller elongations Schaefer's lunar brightness model seems to fit Danjon's data (and a set of observations across the USA spaced by one lunation), Schaefer (1991) does not explain the limb-lengthening at elongations greater than 40° as observed by Danjon. Perhaps it would be necessary to collect fresh data covering a wide range of geographical locations and period (Danjon's data cover a wide range of elongations and span 27 years) and examine this issue more thoroughly. For the moment, it suffices that the observed phenomenon is real and indicative of the limitation to the lunar crescent sighting.

The Lowest Limit in Altitude. The observational criterion (ΔZ, ΔA_z) is restricted to ΔA greater than 6° (Fig. 2c) which is reached at about $a_L \sim 21{\cdot}5°$ ($\Delta A_z \sim 20°$). It has been assumed that for all azimuth separations greater than this (i.e. $a_L > 21{\cdot}5°$) this lower limit of ΔA would apply. This limit however represents the limit of the 'range of the critical original data' used for developing the criterion. In the intercomparison study (Ilyas 1984b), an extension of the a_L range to a few more degrees was made through a linear extrapolation of the Maunder curve and its application to very high latitudes. The inverted data obtained over just a few years did not reflect the importance of the criterion at very large elongations. However, while working on the long-term global data for various locations including very high latitudes, it was found necessary that the criterion be extended to very large elongations appropriately.

Bruin's work enables us to extend the criterion to higher elongations with the help of curves for larger crescent's width, w (a_L) with some interpolation (Ilyas 1988). The convergence of the larger w curves at ΔA minima ($h+s$) in the Bruin criterion leads to a limiting altitude separation of about 4° and necessitates a slight revision of the earlier extrapolation by Ilyas (1981) over the range 21–26° (Fig. 4). The revised ΔA, a_L criterion including both limits is shown in Fig. (5). The Royal Greenwich Observatory's simple rule (RGO 1979) of $\Delta A > 8°$ and elongation, $a_L > 10°$ compares well with the revised criterion. In a more recent work, Ilyas (1988) has extended the Maunder form of the criterion at large azimuth separation (ΔAz) as shown in Fig. 5.

4.3 *Simplified criterion*

Moon's Age. Although use of a comprehensive criterion in a calculation system provides accurate and detailed information on first visibility, it is still desirable for a simpler basis to be developed.

The Moon's age—beginning at conjunction—is a rather simple and easily accessible quantity which has been widely used as a rough indicator of the earliest visibility. However, until the work of Ilyas (1983a), this had been carried out on the basis of rather limited random observations and personal experiences. Therefore, the age-criterion has been in the form of general rules like (Ashbrook, 1971, 1972) "on the basis of recorded accounts, sightings of the Moon younger than 20 h are rare and sightings of the Moon older than 24 h are not uncommon although the visibility may at times require it to be more than 30 h old" and the Royal Greenwich Observatory's general ruling of "more than 30 h old" (RGO 1979). In an earlier work, Ilyas (1978b) introduced the concept of "same age at local sunset" and suggested the use of '24 ± 2 h' age criterion. In a subsequent work, Ilyas (1981) had tried to improve upon these general rulings with the help of global International Lunar Data Lines (ILDL) and 24-h-age lines, for four dates in 1979, drawn together. This limited study was useful in providing a better age estimate for the apex of the ILDL as 22 ± 2 hours. However, it was only after the development of the global computation system (Ilyas 1982a) that a systematic investigation of the age criterion could be undertaken. For this study (Ilyas 1983a), the computation system was used to determine the Moon's age at each visibility longitude just meeting the minimum astronomical conditions.

The data were calculated for various latitudes and about 70 consecutive lunar months. The results, plotted as a function of season (day number of the year) are shown in Fig. 6 for three latitudes. The results exhibit a similar pattern at all latitudes showing variation with the time of year. The scatter in the data results in a band of values leading to an envelope giving upper and lower limits of age requirements at each latitude (the data at 60° may need slight revision to account for slight modification to the basic criterion at large elongations). Although the variation in the age requirement at higher latitudes is too large, the data do provide a far more sound basis of estimation than the earlier general rulings mentioned above. At the lower latitudes—especially in the equatorial and subtropical region—the results are very useful. The results also show why the observational estimates in the past have varied so greatly; latitudinal dependence had been mixed up. The lowest limit of about 16 h (at 0°) is consistent with the sighting records and the rejection of a 14-h old sighting by Ashbrook (1971) appears to be correct.

The present results on the age criterion are more detailed and compare well with the two studies quoted by O'Neal (1975). These include calculations by Schoch (1928; see O'Neal, 1975) for Babylon (32° 30′ N) and another latitude (51° N) who gives (in brackets are results from the present author's work) the minimum age as 16·5 h (17) and 20 h (20) and the maximum age as 42 h (34) and 63 h (56) for the two latitudes respectively. The other study by Bickerman (1968; see O'Neal 1975)—apparently somewhat tied to observations—refers to Athens (38° N) giving 23 h (19) and 69 h (40) for minimum and maximum ages and the figures are somewhat higher. Bickerman is reported to have accepted Schoch's values for Babylon (O'Neal 1975).

Moonset Time Lag. Although the new Moon's age at local sunset provides the simplest astronomical criterion for earliest lunar visibility, we have seen that the age criterion can be used meaningfully mostly at lower latitudes.

The local time lag between moonset and sunset is another criterion that found its extensive use with the Babylonians and the later astronomers. However, this does not seem to have received much further attention. Ilyas (1985) extended the use of a global calculation system to investigate the moonset-lag criterion. In this study, the moonset lag at local sunset was calculated for each earliest longitude—meeting the astronomical criterion—for various latitudes and for 70 consecutive lunations. The results are shown in Fig. 6 from which we see that the 'moonset-lag' provides a simple yet accurate basis of earliest lunar visibility prediction at almost all the practical latitudes (the 60° data may need slight revision to account for the more recent revision of the criterion at large elongations). At the lower latitudes, it provides an excellent, almost constant, basis and compares well with the widely used Babylonian, Hindu and Muslim rule of "greater than 48 min ($a_S > 12°$)", applicable to the mid tropical region. For general use, the results may be summarized as follows in Table III.

Of course, the 'single figure' older criterion is general and too simple for use at different latitudes, especially at the higher latitudes. This figure may be obtained from the simple considerations that the Moon needs to be about 1 day old for earliest visibility (in tropics) and that it lags behind the Sun by an average 49 min per day in transiting a meridian (upper transit, set, rise) (Ilyas 1987). We may also clearly see the inadequacy of a calendrical conference suggestion (Calendar Commission 1978) that for observability the Moon should be at least 8 h old. This is of little practical utility since in that period generally the Moon would attain a typical 4° separation and the moonset lag would be a mere 16 min or so—grossly insufficient. From the results, we note an interesting feature that the data have least scatter in the spring season followed by autumn and winter. The scatter is maximum in the summer which would give rise to a correspondingly larger uncertainty in the prediction. The seasonal dependence would prevail at the southern latitudes and a 6-month hemispherical data shift should be made (Ilyas 1984b).

The moonset lag criterion is simple enough and is perhaps more meaningful to a layman who can now easily understand that the (local) moonset should follow considerably after the (local) sunset and never before (i.e. conjunction must take place well before the local sunset) and can easily estimate the chance of visibility on any (local) evening reasonably accurately. Even for chronological purposes—interpretation of dates in calendars based on the first appearance of the crescent Moon—this criterion offers a simple yet accurate method. Also, the simple moonset lag (and age) criterion allows us to evaluate the reports of sightings from different places conveniently and

TABLE III

Moon-set lag

Latitude	Minimum Moonset Lag (Min)
0°	41±1 (±2 all data)
30°	46±2 (±4 all data)
40°	49±4 (±9 all data)
50°	55±1 (±15 all data)

enables us to ascertain the type of calendrical system being employed at a particular place by examining the observed 'first' dates.

5 CRITERION TEST OF SIGHTING REPORTS AND HUMAN ELEMENT

The role of science in the Islamic calendar has become increasingly important. This is because the world-wide spread of the Muslim community and the availability of instant communication has made the evaluation of sighting claims from different parts of the world a critical matter. Also, numerous man-made objects abound in space and can be easily mistaken for a lunar crescent. Besides, the professional expertise available to individual communities at present is generally low making it easier for those wanting to create mischief or simply looking for the money (the reward given in many places to the first reportee and the witness); it only takes two people out of 1 billion to create confusion.

As Al-Biruni quotes in his famous text, the scientific prediction methods for the new lunar crescent are basically to help test the reliability of sighting reports. For example, if someone reports that they have sighted the new Moon, which we know had set before sunset at the given date and place, then clearly it is a case of mistaken identity of some other object or the *date* of sighting. Due to the fast means of communication, sighting reports from individual countries have been widely accessible to researchers outside those countries indicating that such reports from some countries are consistently erroneous. Two recent studies have further highlighted this problem in Indonesia and Saudi Arabia.

The study of Saudi Arabian dates for 36 months (1410, 1411, 1412 *Hijrah* years) indicated that on 14 occasions the Moon had set before sunset, clearly indicating that the calendar is based on the date of conjunction most probably with reference to Greenwich without regard to the local sunset phenomenon (Ilyas 1993). In the Indonesian study, involving 29 reported observations over a period of 7 years (and claiming to have seen the new Moon near the horizon and occasionally below the horizon), 80 per cent of dates could be rejected on account of errors in dates and reported positions etc. Errors of reported dates and positions are not uncommon even with professionals as found in another recent study of record-setting moon-sighting reports (Schaefer *et al.* 1993). We wish to examine the collective data on Moon sighting reports in a systematic form. But first we consider a widely reported set of recent Indonesian observations referring to the Muslim Fasting month and *Eidul-Fitr* 1412H (1992) (Ilyas 1993a, b).

For the *Ramadhan* 1412H (*Hijrah*), four ASEAN countries (Malaysia,

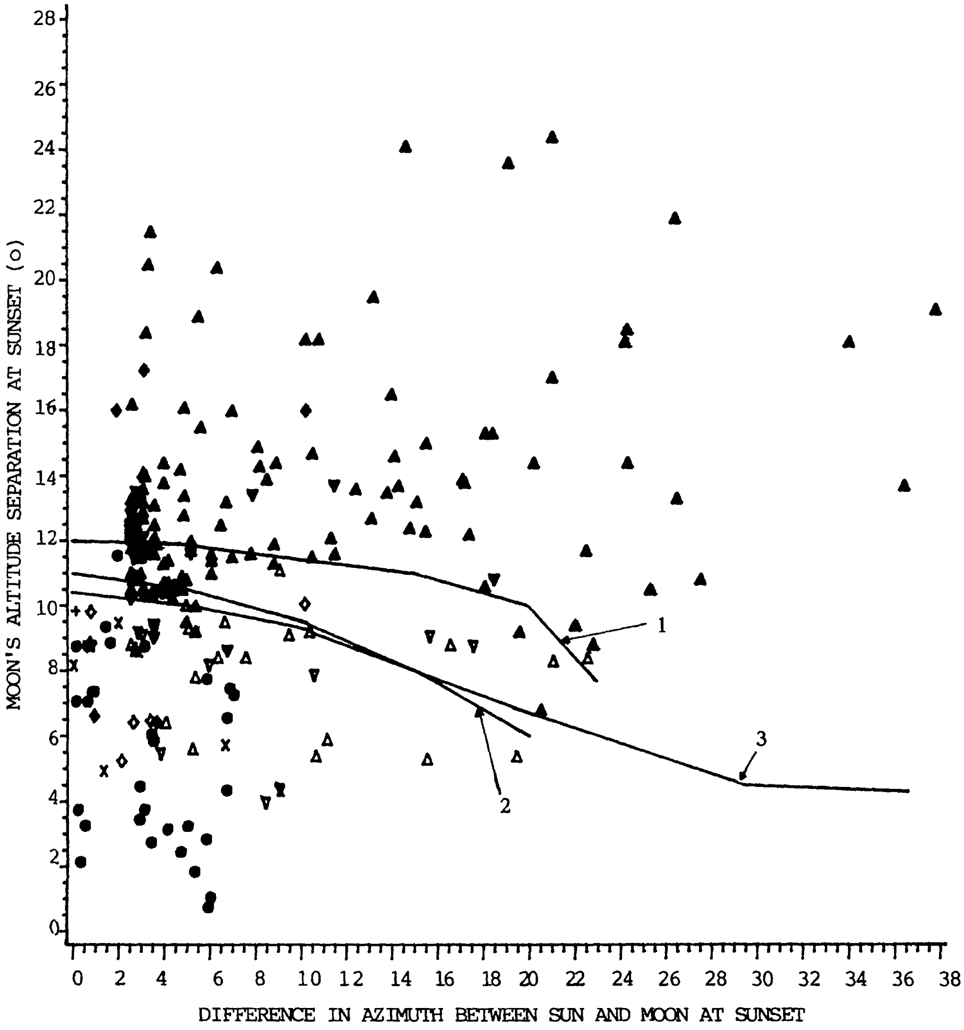

FIG. 8. Comparison of the reported sighting reports available in the literature with the three criteria [1: Fotheringham (1910); 2: Maunder (1911); 3: Ilyas-composite (1988)]. Filled symbols indicate a positive sighting report, unfilled symbols indicate a negative sighting report. Most of the positively reported Indonesian data lie well below the criterion and some close to the horizon at sunset: △/▽ Schaefer (1988) (▽ for morning); ◇ Table IVc, ×/+ Table IVb, ○/⊕ Table IVa, ⊕ indicates that the reported positional parameter is not consistent with the calculated positional parameters (Indonesian Reports).

Indonesia, Brunei, Singapore) agreed to sight the new Moon on March 4, 1992 (New Straits Times, 1992 February 14). The Lunar conjunction took place on: 1992 March 4 at 13:22UT or 21:22MST (Malaysian Standard Time). Calculations show that the Moon set before sunset on this date and thus it is practically meaningless to go for the sighting of the new Moon. (However, one must try to sight the Moon on each 29th of the Islamic date. This simply means that it is crucial that the beginning of *each month* is ascertained carefully and on the expected visibility basis. However, if the calendar is generally constructed on a basis other than the expected visibility then often one would encounter an awkward situation like this.)

Let us examine the situation for the new Moon of *Shawwal 1412H* (i.e. end of Fasting month) (Ilyas 1993a, b). The conjunction occurred on 1992

TABLE IV

Moon sighting reported data (the order of the data has been rept. as it appears in the original reports for easy reference)

Positional analysis of recent observational reports (a) Indonesian (1991) *(b) Schaeffer et al* (1993) *(c) Qurashi* (1991).

(a) Indonesia (PRTI 1991)

	Date (1)	Place (2)	Lat (3)	Long (4)	AltS (5)	AzmS (6)	AltM (7)	AzmM (8)
1.	15.01.1964	Bandan Acol, Jakarta	6·08 S	106·45 E	−0° 44′	248° 32′	+6° 27′	248° 49′
2.	02.12.1967	Projek Ancol, Tanjung Periuk	6·08 S	106·45 E	−0° 52′	247° 53′	+9° 53′	243° 21′
3.	02.12.1967	Desa Gapura, Bekasi	6·12 S	106·53 E	−0° 42′	247° 54′	+10° 02′	243° 22′
4.	06.09.1975	Projek Ancol, Jakarta	6·08 S	106·45 E	−0° 46′	276° 33′	+6° 51′	269° 36′
5.	06.09.1975	Pelabuhan Ratu, Sukabumi	7·00 S	106·32 E	−0° 44′	276° 33′	+6° 59′	269° 44′
6.	02.07.1981	Pelabuhan Ratu, Sukabumi	7·00 S	106·45 E	−0° 46′	293° 07′	+8° 10′	292° 24′
7.	11.06.1983	Pelabuhan Ratu, Sukabumi	7·00 S	106·45 E	−0° 52′	293° 08′	+2° 34′	293° 41′
8.	06.04.1989	Pelabuhan Ratu, Sukabumi	7·00 S	106·45 E	−0° 46′	276° 29′	+1° 12′	281° 56′
9.	20.12.1968	Sukabumi	7·00 S	106·32 E	−0° 46′	246° 16′	+9° 48′	242° 31′
10.	06.11.1972	Dep. Trankop, Jak. Selatan	6·08 S	106·45 E	−0° 44′	253° 45′	+2° 38′	248° 38′
11.	26.10.1973	Bekasi	6·12 S	106·53 E	−0° 53′	257° 21′	+1° 42′	252° 31′
12.	05.10.1975	Projek Ancol, Jakarta	6·08 S	106·45 E	−0° 48′	265° 19′	+2° 30′	261° 06′
13.	05.10.1975	Monumen Nasional, Jakarta	6·08 S	106·45 E	−0° 48′	265° 19′	+2° 30′	261° 06′
14.	11.08.1980	P. Ampenan, Lombok Mataram	8·36 S	116·07 E	−0° 47′	285° 13′	+6° 23′	248° 33′
15.	11.08.1980	Pelabuhan Ratu, Sukabumi	7·00 S	106·32 E	−0° 55′	285° 10′	+6° 34′	284° 17′
16.	11.08.1980	Cakung, Jakarta	6·08 S	106·45 E	−0° 48′	285° 09′	+6° 40′	284° 09′
17.	31.07.1981	Gatot Subroto, Jakarta	6·08 S	106·45 E	−0° 50′	288° 15′	+3° 03′	288° 36′
18.	21.07.1982	Pantai Kastela, Ternate	0·50 N	127·19 E	−0° 52′	290° 31′	+8° 00′	290° 44′
19.	21.07.1982	Ldg. Dawan, Mataraum	8·36 S	116·07 E	−0° 49′	290° 36′	+8° 12′	292° 17′
20.	21.07.1982	Pelabuhan Ratu, Sukabumi	7·00 S	106.32 E	−0° 49′	290° 33′	+8° 39′	292° 01′
21.	29.06.1984	Negri, Pare-pare	4·00 S	119·40 E	−4° 42′	293° 13′	+2° 53′	296° 16′
22.	29.06.1984	Kg. Baru, Bekasi	6·12 S	106·53 E	−0° 44′	293° 16′	+3° 09′	296° 30′
23.	28.05.1987	Pelabuhan Ratu, Sukabumi	7·00 S	106·32 E	−0° 44′	291° 29′	+6° 39′	298° 38′
24.	28.05.1987	Manado	1·32 N	124·55 E	−0° 42′	291° 26′	+7° 14′	297° 16′
25.	16.05.1988	Cakung, Bekasi	6·12 S	106·53 E	−0° 47′	289° 14′	+3° 46′	296° 00′
26.	25.04.1990	Ujung Pangka, Surabaya	7·12 S	112·38 E	−0° 47′	283° 11′	+0° 08′	289° 14′
27.	25.04.1990	Cakung, Jakarta Timur	6·12 S	106·53 E	−0° 42′	283° 11′	+0° 32′	289° 19′
28.	25.04.1990	Banda, Acheh	5·30 N	95·20 E	−0° 56′	283° 20′	+2° 05′	289° 14′
29.	09.04.1986	Pelabuhan Ratu, Sukabumi	7·00 S	106.32 E	−0° 50′	277° 31′	+1° 31′	277° 56′
30.	18.02.1988	Lhoknga, Acheh Besar	5·30 N	95·20 E	−0° 47′	258° 13′	+0° 53′	260° 14′
31.	18.03.1988	Mes. An-Nur, Pakan Baru	0·33 N	101·30 E	−0° 48′	269° 15′	+3° 48′	272° 16′
32.	14.07.1988	Tanjung Kodok, Gresik	7·12 S	112·38 E	−0° 42′	291° 42′	+5° 19′	295° 16′
33.	14.07.1988	Pelabuhan Ratu, Sukabumi	7·00 S	106·32 E	−0° 50′	291° 41′	+5° 24′	295° 12′

34. 03.07.1989	Pelabuhan Ratu, Sukabumi	7·00 S	106·32 E	−0° 41′	293° 02′	+2° 13′	296° 36′
35. 01.08.1989	Pelabuhan Ratu, Jakarta	7·00 S	106.32 E	−0° 44′	288° 01′	−3° 02′	290° 06′
36. 23.06.1990	Bekasi	6·12 S	106·53 E	−0° 50′	293° 29′	+8° 04′	296° 43′
37. 25.09.1989	Ditbinbapera		Wrong Date (Conjunction occurs on 1989 Sept. 29 at 2146 UT)				

(b) Schaefer *et al.* (1993)

Date (1)	Place (2)	Lat (3)	Long (4)	AltS (5)	AzmS (6)	AltM (7)	AzmM (8)
38. 06.12.1885	Paris	48·85 N	2·33 E	−0° 52′ 47″	235° 28′	+4° 03′ 39″	236° 53′ 25″
39. 22.07.1895	Faversham	51·32 N	0·90 E	−0° 52′ 23″	304° 50′	+4° 56′ 32″	298° 05′ 59″
40. 10.02.1910	Tunbridge	51·08 N	0·15 E	−0° 49′ 56″	247° 41′	+3° 34′ 18″	238° 33′ 18″
41. 02.05.1916	London	51·50 N	0·12 E	−0° 52′ 36″	296° 30′	+7° 22′ 44″	296° 24′ 28″
42. 05.05.1989	Mt. Baldy, New Mexico	34·08 N	106·95 W	−0° 50′ 55″	290° 38′	+8° 31′ 37″	292° 41′ 55″
43. 05.05.1989	Houston	29.77 N	95·35 W	−0° 49′ 18″	289° 34′	+7° 51′ 15″	292° 29′ 19″
44. 05.05.1989	East Lansing, Michigan	42·75 N	84·50 W	−0° 49′ 44″	293° 33′	+8° 08′ 14″	294° 21′ 45″
45. 05.05.1989	Grand Rapids, Michigan	43·00 N	85·75 W	−0° 53′ 45″	293° 48′	+8° 07′ 33″	294° 21′ 47″
46. 05.05.1989	Lake Travis, Texas	30·45 N	98·00 W	−0° 52′ 36″	289° 44′	+7° 56′ 53″	292° 32′ 07″
47. 24.05.1990	Mt. Wilson, California	34·23 N	118·05 W	−0° 53′ 18″	296° 10′	+9° 01′ 56″	296° 00′ 21″

(c) Qurashi (1991)

Date (1)	Place (2)	Lat (3)	Long (4)	AltS (5)	AzmS (6)	AltM (7)	AzmM (8)
48. 28.04.1987	Peshawar	34·01 N	71·40 E	−0° 48′	287° 39′	+05° 49′	288° 37′
49. 06.04.1989	Islamabad	33·40 N	73·08 E	−0° 56′	278° 30′	+05° 38′	281° 09′
50. 06.05.1989	Islamabad	33·40 N	73·08 E	−0° 51′	290° 39′	+15° 04′	300° 53′
51. 26.02.1990	Dadu	26·42 N	67·48 E	−0° 45′	260° 40′	+15° 15′	262° 36′
52. 27.03.1990	Islamabad	33·40 N	73·08 E	−0° 49′	273° 41′	+10° 00′	276° 21′
53. 25.04.1990	Islamabad	33·40 N	73·08 E	−0° 44′	286° 25′	+05° 53′	289° 49′
54. 25.04.1990	Lahore	31·34 N	74·22 E	−0° 49′	286° 03′	+05° 36′	289° 43′
55. 18.12.1990	Islamabad	33·40 N	73·08 E	−0° 45′	242° 10′	+09° 28′	232° 01′
56. 16.01.1991	Islamabad	33·40 N	73·08 E	−0° 48′	245° 11′	+04° 36′	243° 02′
57. 15.02.1991	Islamabad	33·40 N	73·08 E	−0° 54′	255° 18′	+09° 04′	256° 06′
58. 19.03.1991	Cairo, Egypt	30·03 N	31·15 E	−0° 56′	268° 58′	+16° 18′	272° 05′

(1) Date: ddmmyyyy; (2) Place of observation; (3) Lat: Latitude; (4) Long: Longitude; (5) AltS: Altitude of Sun; (6) AzmS: Azimuth of Sun; (7) AltM: Altitude of Moon; (8) AzmM: Azimuth of Moon.

April Friday 3 at 05 h 02 min UT i.e. 13 h 02 min Malaysian time. For Penang (5° 25′ N, 100° 12′ E), Malaysia, we find that on 1992 April 3, the sunset time is at 19 h 28 min and the moonset time is 19 h 31 min. The Moon's (true) altitude at sunset time is 42′ which together with parallax (56′) would give the Moon's apparent altitude for observation at the Earth's surface as 42′–56′ = −14′. The Moon could not be seen.

Also, at *Grisek* (7° 7·2′S, 112° 22′E), East Java, Indonesia, 1992 April 3, the sunset time was 17 h 34 min and the moonset time was 17 h 30 min (before sunset); the Moon's (true) altitude at sunset being −0° 50′ meant that the Moon could not be sighted.

Indeed, the global data would show that the new Moon of *Shawwal* could not be sighted on April 3 in South-East Asia (or Africa) but it was sightable in the western part of America. On April 4, the new Moon could be sighted over most of the world as graphically presented in the Malaysian papers (*New Straits Times*, 1992 April 4; Berita Harian, 1992 April 4). However, it is well known that nearly half the Indonesians (under *Nahdatul Ulama–NU*) and many in South Thailand (close to Penang) celebrated 1st of *Shawwal* 1412H (*Eidul-Fitr*) on April 4 claiming that they have seen the (new) crescent Moon on the evening of 1992 April 3 (for more details see Ilyas 1993a).

Also, it was reported (Berita Minggu, 1992 April 5, p. 2) that in South Thailand, the *Eidul-Fitr* was celebrated on Friday 1992 April 3, the new Moon presumably having been sighted on April 2!

Occasionally we find that individuals hang on to such rare and unreliable reports giving them importance far in excess of their statistical and scientific significance. This human element only complicates the resolution of this problem in a proper manner. To further highlight this and review the scientific criteria and underscore the importance of scientific data and the visibility criterion we have analysed about 300 reported critical records from all over the world and available in the literature which clearly confirm that the present scientific reported criterion still remains the best prediction basis for average viewing conditions and can easily discern wrong sighting reports.

A valuable observational data set including the Athens data was summarized in a recent study (Schaefer 1988). A series of reports have provided additional data for Indonesia (PRTI 1991; Ilyas 1992), Pakistan (Qurashi 1991) and for some record-setting sightings (Schaefer *et al.* 1993). We have re-analysed the information for the last three sets of data to evaluate the various positional parameters. The entire available reported data from the four sets is presented in Fig. 8 together with the criteria given by Fotheringham and Maunder and the Indian (Schoch)—Ilyas (extended) composite criterion. It is clear that a large number of Indonesian data of positive sightings are far below the criteria and certainly not acceptable. So are the two critical observations in the Pakistan data and several reports in the record-setting data set (Table IV). In another study, McPartlan (1991) has compared the composite criterion with early Islamic observational reports and found that it is generally consistent although a slight downward revision (by about 0·5°) may be made (Fig. 9). Of course, his data must refer to somewhat better conditions of viewing in the 6th century AD and thus we can say that the present criterion represents a reasonable basis for average atmospheric conditions. The fact that we did not separate the data according

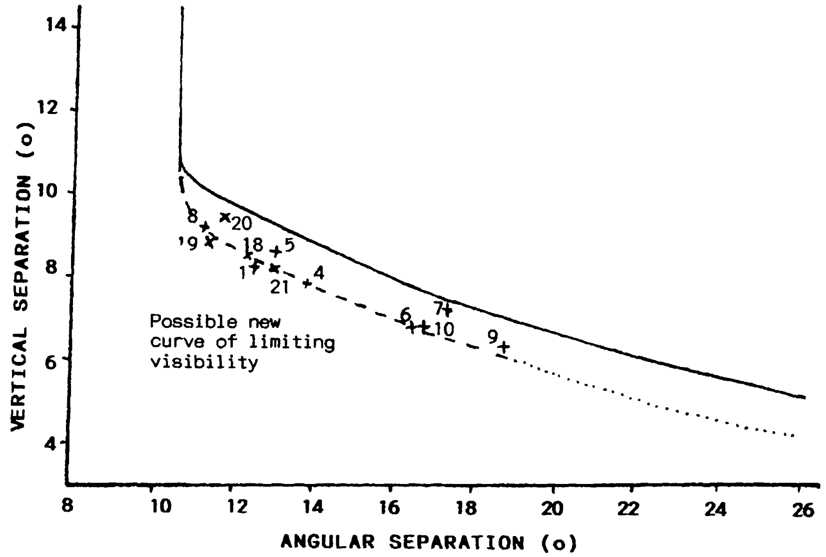

FIG. 9. Comparison of Ilyas's composite criterion with data from historical records from 6th century Hijrah (McPartlan 1991).

to extinction of the sighting place and yet we see the lower threshold to remain close to the composite 'average conditions' criterion is reflective of its relevance for use in general purpose long-term global (expected) visibility calendrical data generation.

6 ACCURACY OF THE CRITERION AND ATMOSPHERIC CONDITIONS

Although calculations of earliest visibility longitudes, L_0, may be done with great precision, at present a computational accuracy in L_0 of less than 1° to 2° in geographical longitude is not of much practical utility since the criterion has an uncertainty of a greater magnitude. The observational Maunder criterion was considered to be in error by about 1° in altitude separation (e.g. the Indian Ephemeris lists a certainty region beyond $+1°$ altitude separation). On the other hand, in view of the internal consistency between the Maunder and Bruin criterion over the overlapping region and since the latter is reported to be accurate to within a few minutes, it was considered that the Maunder criterion has an accuracy of the same order (Ilyas 1981). However, this was reconsidered recently by Ilyas (Ilyas 1982a). Although Bruin's observational experience testifies to the accuracy of his criterion at his Beirut location (35° N), it seems that he would have been close to an earliest global visibility line (ILDL) only rarely. This is reflected in the fact that he observed considerably wider crescents and his criterion for earliest visibility required a wider crescent than did the Maunder criterion which is applicable to lower latitudes.

We also note that Schmidt's observations at Athens were also usually confined to considerably older crescents and this consideration led Maunder to revise the original Fotheringham criterion downward and the Indian (Schoch) version is a further downward revision (see Ashbrook 1971). In Bruin's criterion, extended to smaller separations (a_L) i.e. in the vicinity of L_0 at lower latitudes, the variations in such variables as sky brightness, crescent intensity, observable contrast, etc. would become significantly larger. Therefore, it would seem safe to assume an error of about ±1° in altitude separation. This means that if the actual altitude separation is greater, by 1°, than the required value of the criterion, positive visibility would be certain and if less, by 1°, than the required value, negative visibility on the specific evening is certain. This would translate into an uncertainty region of about ±30° in longitude in the first visibility longitudes (L_0) determined using the present criterion. The error of ±1° is consistent with the spread in the data between the Bruin and inverted Ilyas criterion (Ilyas 1981). Perhaps an error of about half as much would have about 80–90 per cent confidence level up to middle latitudes. Bruin indicates a better accuracy of his technique from field tests (Bruin, personal communication).

The effect of this error in the criterion on the predicted data is not very serious. What this means is that around the first visibility longitudes and the associated ILDL, there is a small region of about ±30° longitude around the ILDL where the visibility is uncertain (Fig. 7). Over the rest of the global surface, we can determine the date with greater certainty. This point is illustrated further elsewhere in the context of the calculation and application of (global) International Lunar Date Lines (ILDLs).

The earlier understandings, such as (McNally 1980) "...whether observatory scientists have been able to set a standard by which you can be certain of the evening when a new Moon will appear, then I am afraid the answer is no..., one can specify a certain angle but there is always just a chance that someone with particularly keen sight, in a particularly steady and clear atmosphere, might just be able to detect the Moon prior to its reaching its statutory position" or (RGO 1979) "It is not possible to predict accurately the dates on which the new crescent Moon will first be seen each month since...' may now be considered to apply to the uncertainty zone only—whatever its width—as a result of the global application study by Ilyas (1981; 1982a).

Obviously, one of the future tasks should be to try and reduce this uncertainty in the criterion. That would mark a further significant development from our previous uncertain situation which McNally (1980) put very nicely, "...I am sorry to say there is no scientific way, I think, in which the requirements of Islam (*of certainty*!) can be met *at the moment*" (my emphasis and brackets). This of course is now true for the zone of uncertainty around the ILDLs only. (30-year global data on ILDLs are available in Ilyas (1984b)—for a sample see Table 1.) Nevertheless, we need to have an overall view of the input variables. Any astronomical prediction criterion involves the use of a set of variables (necessary contrast for the human eye, sky brightness, crescent's light, atmospheric condition and its effect on the light, etc.). For a particular set of conditions, a specific criterion can be established. Thus, in principle, we can have a system in which the values of these variables can be adjusted to produce an appropriate criterion.

However, it is desirable to establish a single criterion in which various variables are optimized. This can be done directly in a physical model of the Bruin type or in an observational model of the Maunder-Fotheringham type. Although development of a general purpose Islamic calendar is based on the expected visibility information, the need for long-term data and certain overriding considerations (like 'visibility at one place suffices for the whole country or a certain region') facilitates the practical use of an optimized prediction criterion. Also, at times a change in the value of one variable may be compensated by a change in another variable's value between two different situations. For example, a worsening of atmospheric clarity (extinction) may be compensated by the improvement of a person's ability to see fainter objects (for new records of youngest Moon sightings see RASCN 1989; S&T 1989). Therefore, for long-term global reference data generation, there are certain advantages for the adoption of an optimized criterion for a certain period (say 5–10 years), as adopted at the Penang Declaration 1991 (Ilyas & Zhari 1992). During this period, observational data can be organized to provide meaningful information to cover varying conditions on a global scale and help review and revise the criterion in a practical way. Indeed, a general proposal involving about 15–20 centres for a coordinated research project was approved by the Science Ministers Committee under the Organization of Islamic Conference (OIC) in 1991. A follow up action plan is being drawn up with considerations of religious and other control aspects under the *International Islamic Calendar Programme* (*IICP*). The newly established Sheikh Tahir Astronomical Centre (STAC) in Penang would play an important role in this work.

To illustrate how a change in the adopted value of a variable can shift the location of the first visibility line, we consider the case of atmospheric clarity which is technically represented by an atmospheric *extinction factor*. It is common knowledge that for places like the deserts where the atmosphere is more transparent (smaller extinction factor), it is easier to see fainter stars and other objects including a less bright lunar crescent. On the other hand, in regions where the atmosphere is less transparent (or greater extinction factor) such as industrial sites and polluted cities, it would require an object to be brighter for sighting. In the context of a visibility criterion, we have adopted the composite Bruin-Maunder criterion applying to a relatively clear atmosphere (good viewing conditions) for some of the practical considerations discussed earlier. Nevertheless, additional corrections can be made to account for significant changes in the adopted variables including the atmospheric extinction. But, it is more meaningful to establish the long-term behaviour of dominant geographical regions and a set of separate criteria may then be established for each such region. For instance, very early it was considered that the Maunder criterion may need modification at higher latitudes because of changes in the atmospheric clarity (e.g. see Reynold 1939; Ilyas 1984b). Of course, a prediction is always made in advance. What exact weather conditions would prevail at a given place on a future evening can not be easily pre-determined (climate and weather pattern have been undergoing serious changes lately!) but an average behaviour (within the definition of good or clear weather) may be established. To establish a demarcation about the limit to 'good weather' modelling of the atmospheric conditions (after which it must be considered as bad weather within religious consideration) is of practical importance in the context of the Islamic calendar.

Nevertheless, to show the effect of changes in atmospheric extinction, we use a simple model (several models are available; I used one by Waddington,

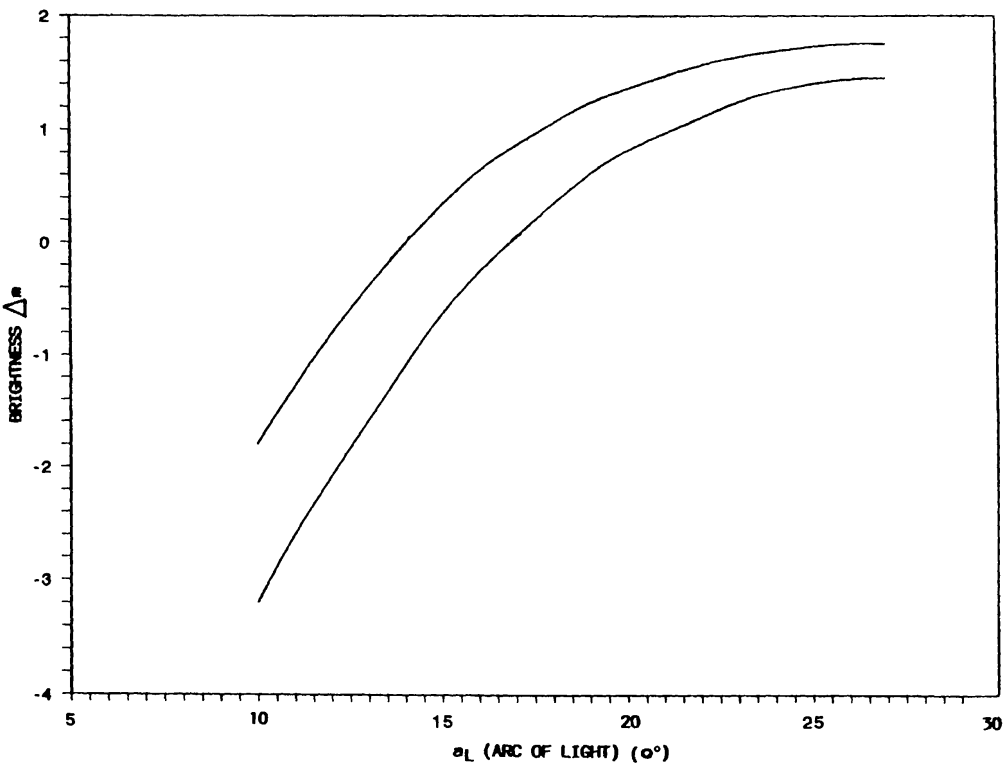

FIG. 10. In this figure, we illustrate how extinction variation can change the brightness of an object; the effect of an increase in atmospheric extinction is to shift the earliest visibility of new Moon to western longitudes. We take a typical case where the Sun is at 6° altitude below the horizon which is about 20 minutes after sunset at a sub-tropical latitude and a favourable situation for young crescent Moon sighting. The upper curve shows the calculated brightness of the Moon as a function of elongation (a_L), under good viewing condition ($T \sim 0{\cdot}15$). The lower curve shows the calculated brightness for an extinction increased by 0·1. For the same extinction change, the decreasing effect at large elongations is due to decreasing air mass (M) for the Moon's increasing altitudes at these elongations. Thus, we notice that mostly the effect of extinction variation would be more serious at smaller elongations ($a_L \sim 10°$) when the Moon is closer to the horizon. An increase in the atmospheric extinction can be compensated by a westward shift in the longitude for earliest visibility of the new Moon (at local sunset) which leads to an increase in the elongation and the Moon's altitude above the local horizon.

personal communication) to calculate the brightness of the lunar crescent at different elongations and at two different extinctions. We may note (Fig. 10) that a change in extinction by 0·1 produces a change in brightness which can be compensated by a change in elongation varying from about 2–3° at smaller elongations (lower latitudes) to about 4–6° at larger elongations i.e. a geographical longitudinal shift of about 75° and 150° respectively. Thus a crescent Moon will need to grow bigger to be sighted if the extinction is greater. This simple fact was presented in a somewhat complicated way in recent reports (Doggett *et al.* 1988, Doggett & Schaefer 1989) and other related papers (e.g. Schaefer 1988) in which repeated qualitative discussions of a 'Bruin-type' prediction system have been made although actual information on the criterion has yet to be made available (Ilyas 1989b). The results of Fig. 10 are consistent with a similar study reflecting the extinction effect on ILDL in shifting the earliest visibility line for a specific date

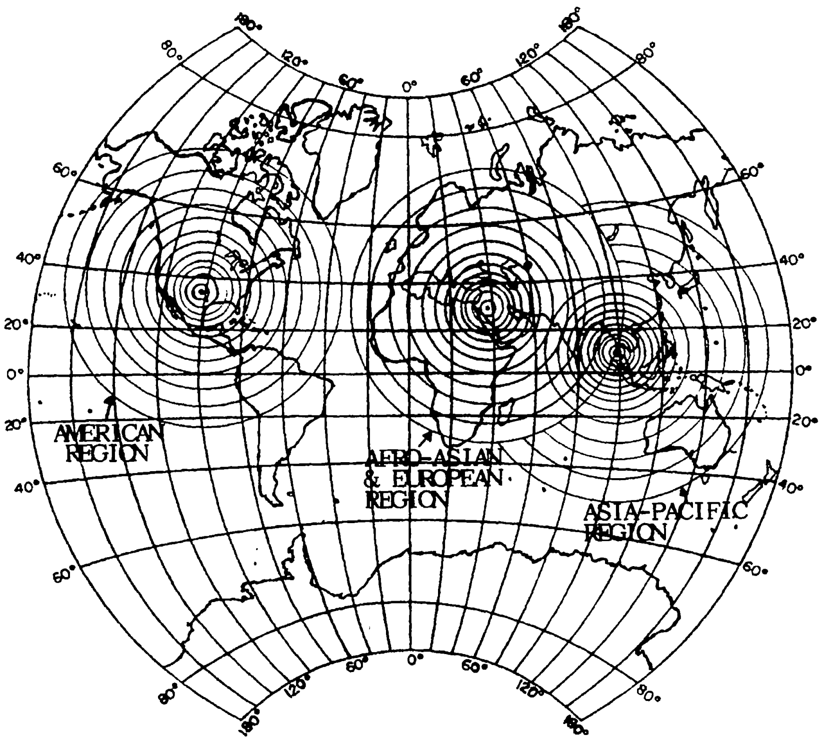

FIG. 11. Three zones for the construction of zonal calendars.

(Doggett & Seidelmann 1988). However, one could introduce a micro-scale adjustment for extinction variation for the same date and thus for the changed shape of the visibility prediction line (Doggett *et al.* 1988).

It is ideal to be able to model the prediction system to a great precision on a micro-scale i.e. place to place basis involving some complexity. However, for long-term prediction, it is not practical to be able to build into the model, actual weather conditions which vary on a day to day time scale. Therefore, at best one can incorporate a geographically-dependent general (average) state of atmospheric condition (clarity). Also, in the context of Islamic calendrical regulation, a number of practical considerations lead to considerable simplification as follows.

(1) The sighting of the new crescent Moon at any one place suffices for a certain geographical domain. The exact extent of it is subject to theological considerations but certainly it would cover a group of nearby countries (e.g. the Gulf region and the Indo-Malay region already make use of this). This amounts to shifting the practical ILDL to the easternmost boundary of the country/region. Thus the ILDL drawn for the July 1988 Moon watch (Doggett & Schaefer 1989) would need to be shifted to the eastern boundary. Indeed, the fact that there were a few definitive observations along the eastern border of the USA is sufficient to draw the line there. The prediction line based on Ilyas' 30-year advance data (Ilyas 1984b) is clearly reflective of this. For the establishment of a general purpose (administrative) unified calendar, the world has now been divided into three broad zones (Fig. 11) each with a regional calendar (Ilyas 1994, Ilyas & Qurashi 1993). Thus it is not necessary to be able to sight the new Moon at each and every place.

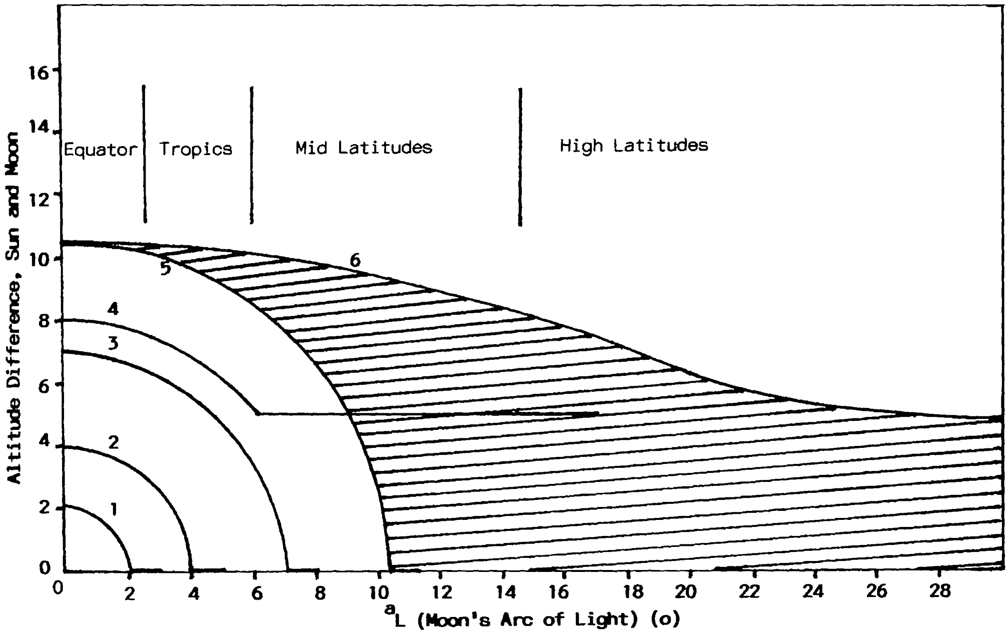

FIG. 12. A summary of various criteria in use; Moon above the curve is expected to be sightable: 1:2° criterion reporting observations in SEA; 2:4° Indonesian SEA criterion; 3:7° Danjon Limit; 4: Istanbul 5°/8° criterion; 5: Revised Danjon Limit (1983); 6: Modern Composite Criterion (Ilyas 1988).

(2) Within a broad region/country/zone, any place that offers the best viewing conditions and/or is furthest to the west would form the basic reference for calculations.

(3) It is better to make optimistic calculations of ILDL (for average viewing conditions) which would serve as an easternmost demarcation line for earliest visibility and this would rule out 'sighting' undercutting the 'predictions'. On the other hand, sightings shifted to the western side of the ILDL would, in practical terms, influence the ILDL usage eastwards through the 'one sighting for one region' as in (1) above.

(4) The bulk of the Muslim community lives in tropical and mid-latitudes and conditions and predictions in these regions would overwhelm the usage elsewhere. Higher latitudes are considered as abnormal zones and time-dependent religious practices are determined according to lower latitudes. At the tropical and sub-tropical regions, there are vast areas of deserts and places with good viewing conditions and these places will help in utilizing early sightings at higher latitudes and not so 'clear' places/regions.

(5) If one were to go to higher altitude to view the new crescent, it would help through the delayed times of sunset and moonset due to depression of the local horizon. A person at about 10 km would gain about 25–30 min extra for viewing which is equivalent to going westwards by about 7–8° in terrestrial longitude. Hence, besides overcoming the cloud effect, one could compensate, at least partly, a bad viewing atmospheric condition at a given place. Indeed, this issue of using aircraft has been under examination in recent years.

The net effect of the above considerations is such that for practical purposes, we should optimize the calculations for average tropical conditions

TABLE V

Expected Visibility Criteria: Approximations for Lunar Calendar Regulation

oth Order (synodic month based)		Schematic; approximately alternate months between 29 and 30 day with some intercalatory days
Ist Order (conjunction based)	(a)	Conjunction before midnight (some reference location)
	(b)	Conjunction before sunset (local place)
IInd Order (sun–moon–time lag)	(a)	A certain Moon's age at local sunset (latitude dependent)
	(b)	A certain moonset lag from sunset at the place (latitude dependent)
IIIrd Order (one parameter positional separation)	(a)	Babylonian (12°) rule
	(b)	Danjon Limit (7°) elongation rule
	(c)	Indonesian (2°) altitude rule
IVth Order (two parameters-average conditions)	(a)	ΔZ, ΔAz Maunder/Fotheringham
	(b)	ΔA, a_L Bruin/Arabian
	(c)	Composite Ilyas—Bruin—Fotheringham
	(d)	*Ad-hoc* combinations (i) Istanbul '8 hr + 8°/5°' (ii) S.E. Asia '8 hr + 5°'
Vth Order (Extinction and other variable dependent)	(a)	Extinction dependent global system
	(b)	Specific location/zone based sets of simple criteria
	(c)	Broad 'latitude—zone' based criteria

and improve the viewing through selection of persons with good acuity and good sites.

In conclusion, the criterion presented here forms a good starting point for practically usable earliest visibility and calendrical data paving the way for the implementation of a Unified World Islamic Calendar (Ilyas & Ismail 1992, Mohamad 1994).

7 OVERVIEW

We may now summarize the discussion and present the state of the astronomical criterion of the new Moon's earliest visibility (Fig. 12 and Tables V, VI). We have noted that scientific work on the astronomical criterion has been undertaken from very early times and the criterion is presented in several forms. Maunder's 1911 criterion remained largely unknown until Ashbrook's mention of it in the early seventies (Ashbrook 1971, 1972). A few years later this information was introduced into the Islamic world by Ilyas (1976, 1977, 1978a, b, 1982b), who also paved the way for its subsequent wider dissemination (and modification) in the modern scientific literature. The composite (observational/theoretical) criterion of Ilyas, as recently modified, represents the latest development. The error in this is estimated to be about ±1° or an equivalent longitudinal error of ±30° in ILDL (Fig. 7). Future work should be devoted to reducing this error, observationally, theoretically—using physical parameters—or both. The newly-derived *Moon's age and moonset lag* criteria of Ilyas provide simpler bases for approximate estimation and the latter is relatively accurate for most

TABLE VI

Summary of the Development of Astronomical Criteria: *BC–1988*

Period	Astronomers	Criterion	Remarks
BC ——	Ancients (Babylonians)	$a_S \geqslant 12°$ (or moonset 48 min after sunset)	Based on observations
BC ——	Chinese Greeks (Aratos, Berossos of Chaldeon (300 BC), Ptolemy)	—	Using Babylonian rule, not much attention to this area
AD 500	Hindus	$a_S \geqslant 12°$	Perhaps based on Ancient's observations (elaborate system of calculations developed and importance of lunar width realized)
767–778	Yaqub Ibn Tariq	—	Tables for calculation
740–840	Habash	—	Calculated system developed
–830	Al-Khwarizmi	$9{\cdot}5° < a_L$	—
731–861	Moses (Ibn Maimon) (Maimonides)	$9° \leqslant a_L \leqslant 24°$ $a_D + e \geqslant 22°$	General Autumn and Spring (calculated system developed)
850–929	Al-Battani Al-Farghani	$a_S < 12°$ (when a_L is large)	
826–901	Thabet b. Qurra	$11° \leqslant a_L \leqslant 25°$	—
–986	Abdul Rahman Al-Sufi	$a_S \geqslant 12°$	Follows Babylonian rule refers to Habash & Battani
	Ibn Sina		—
1258–1274	Nasir Al-Din Al-Tusi		—
15th century	Ghiyath Al-Din al-Kashani	$a_S \geqslant 12°$	As Babylonian; begin sighting 24 min past sunset
1910–11	Fotheringham & Maunder	$a_D(\Delta Z) \geqslant f(Z, A_Z)$	(or $a_S \geqslant 11°–12°$ for $\Delta A_Z = 0$; observational)
1977	Bruin	$a_S(\Delta Z) \geqslant f(Z_{ms}, \omega)$	Theoretical, incomplete and erroneous
1981–84	Ilyas	$a_D(\Delta Z) \geqslant f(a_L, Z)$	Composite of two independent criteria
1983	Ilyas	Age $\geqslant$ f(lat, season, year)	Simpler approximate criterion
1984–88	Ilyas	$a_S \geqslant$ f(lat, season) (moon-set lag (min): 41 ± 2 at 0°, 46 ± 4 at 30°; 49 ± 9 at 40°; 55 ± 15 at 50°)	More accurate, shows quality of Ancient's more general rule for up to mid latitude

practical latitudes of relevance to Muslim populations (at very high latitudes, weather becomes a serious consideration!). Indeed, these simple criteria have been found to be suitable for explaining the science of the new Moon's visibility to the public at large (Malek 1992, Ilyas 1993a, Munshi 1993).

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