Determining the Dates of the Illumination of the Great Temple at Abu Simbel and their Relation to Khoiak

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THE EGYPTIAN GOVERNMENT holds a grand 'Festival of the Sun' at Abu Simbel on 22 October and 22 February, with the understanding that these were the intended dates for a solar phenomenon which occurs biannually within Ramses' temple. There is plenty of documentation of the sun illuminating the temple on these dates, however, the sun rises at different azimuths on these two dates. For example, on 22 February 2018, the sun's azimuth when it breached the eastern hills at Abu Simbel was 100.85º, however, on 22 October 2018, the solar azimuth was 101.7º.[1] The light effect occurred on both of these dates despite there being a difference of 0.85º azimuth. The sun's azimuth only changes by about half this amount each day, so this is a significant deviation.

In February 2018, the azimuth of the sun when it breached the eastern hills at Abu Simbel was within this range on three dates: 20, 21, 22. In October 2018, it was also within this span for three days: 20, 21, 22. These observations of course belong to the temple after its move, but they do confirm that the light phenomenon was not confined to a single day.

There are very few records of the sun illuminating the temple on dates other than 20–22 October and 20–22 February. No ancient recordings of the illuminations have been found. In modern times, the temple was covered in sand until Belzoni exhumed it in 1817. Since then, recorded observations dated prior to the temple's relocation are rare. Amelia Edwards[2] visited Abu Simbel for 19 days in 1874 and wrote:

> It is fine to see the sunrise on the front of the Great Temple; but something still finer takes place on certain mornings of the year, in the very heart of the mountain. As the sun comes up above the eastern hill-tops, one long level beam strikes through the doorway, pierces the inner darkness like an arrow, penetrates to the sanctuary, and falls like fire from Heaven upon the altar at the feet of the Gods.

Amelia departed Abu Simbel on 18 February 1874. The sun's azimuth was at its closest to the temple's axis during her visit on this date: 102.78°.[3] In 1892, the account of A.F.[4] was published in the Pall Mall Gazette:

> I was fortunate in seeing another wonderful thing during my visit to Aboo Simbel. The great

[1] NASA Jet Propulsion Laboratory, *Horizons web-interface* <https://ssd.jpl.nasa.gov/horizons.cgi#top> (25 March 2020 [hereafter JPL]).
[2] A. EDWARDS*, A thousand miles up the Nile*, New York, 1888, p. 276.
[3] Azimuth sourced from JPL.
[4] A.F., "The restoration of Rameses", *The Pall Mall Gazette*, 20 April 1892, p. 2.

> temple is dedicated to Amen-Ra, the Sun-god, and on two days in the year the sun is said to rise at such a point that it sends a beam of light through both halls till it falls on the shrine itself in the very Holy of Holies… It was the 26th of February.

A.F. gives the date of their observation, but did not specify the year. The sun carried an azimuth between 99.57° and 99.86° on 26 February in that era.[5] Both A.F. and Amelia Edward' observations were outside the range established above.

Fortunately, prior to the temple's relocation in the 1960's, a team of scientists was picked by UNESCO to assemble as much knowledge about the temple as possible. The director of the UNESCO office for saving the Nubian monuments Jan van der Haagen[6] observed the sun's rising point over six days, recording them on an image of the temple doorway (as seen from within the temple), showing the dates that the sun rose over the hills outside [fig. 1].

Determining the first day of illuminations in October, 1959

The number of days that the sun illuminated the statue group is necessarily greater than this though, for the sun at Abu Simbel rises at a southerly angle of 66°, meaning that for several days before the sun rose in line with the doorway, it still made an appearance within it (i.e. it crossed the upper left portion of the doorway, when viewed from within the temple).

The problem here is that we cannot know how many days that this extended the span of illuminations for, unless we know the angle from the door's lintel to the inner sanctum.

Fortunately, Haagen [7] also recorded this: "up to 4 degrees, inner sanctuary is fully illuminated". Figure 1 has been expanded upon to presents all the dates in October 1959 that the sun rose outside of the scope of the doorway, but still made an appearance within it due to its southerly angled path. For ten consecutive days the sun rose in line with the temple doorway, illuminating the statue group.

Adjusting the dates of the illuminations in Ramses' era

The sun's rising point on any given day, shifts over time. The effect is minuscule over a span of centuries, but it becomes significant over millennia. For example, the sun's azimuth at Abu Simbel on 18 October, 1959 was 100.21º at sunrise, but on the same date in 1266 BC the sun's azimuth was 100.62º at sunrise.[8]

This represents a significant difference. Note also that because the sun has a four-year loop, it is important to compare four consecutive years to accurately determine the difference that

[5] Azimuths sourced from JPL.

[6] J. HAAGEN, "Rameses' mysterious encounter at dawn", *The UNESCO Courier* 15, Paris, 1962, p. 12.

[7] J. HAAGEN, "Rameses' mysterious encounter at dawn", p. 12.

[8] Azimuths sourced from JPL. Note that for sunrise, moments are calculated for apparent sunrise which occurs 0.567º before the geometric sunrise, however, sunrise occurs when the edge of the sun appears above the horizon, so the apparent radius of the sun (0.267º), therefore the moment of sunrise on a clear horizon is when the sun's apparent elevation is -0.834º; see USNO database <http://aa.usno.navy.mil/faq/docs/RST_defs.php> (10 July 2019). However, the eastern hills delayed the sun's emergence by five minutes at Abu Simbel prior to its relocation; see J. HAAGEN, "Rameses' mysterious encounter at dawn", p. 14. The upper limb of the sun breached these hills when it reached an apparent elevation of +0.3º.

3,227 years has made. The tabulations below compare B.C. azimuths[9] on 18 October (Gregorian), with A.D. azimuths on 19 October (Gregorian).

Solar azimuths at apparent sunrise, Abu Simbel, 18 October 1269-1266 B.C.:

1266 BC = 100.62°;

1267 BC = 100.71°;

1268 BC = 100.82°;

1269 BC = 100.90°.

The mean azimuth for these four years is 100.7625°.

Solar azimuths at apparent sunrise, Abu Simbel, 19 October 1958-1961:

1958 = 100.71°;

1959 = 100.61°;

1960 = 100.91°;

1961 = 100.81°.

The mean azimuth for these four years is 100.76°.

The effect of three millennia has been to shift events by exactly one day.

As shown in Figure 1, the inner sanctum was illuminated by the dawn sun for 10 successive days; these dates were 13 October - 22 October in 1959. The equivalent dates in the 13th century B.C. were 12 October - 21 October.

The summer solstice fell on the first day of the year (I *3ḫt* 1) when the civil calendar and the natural seasons were in harmony with the natural year. This occurred on June 24 in the 13th century B.C.[10] Since *3ḫt* was comprised of four months, each 30 days in length, 12 October - 21 October corresponded to IV *3ḫt* 20 - IV *3ḫt* 29 in that era.

The significance of the illuminations

Any structure aligned to the east at Abu Simbel between the angles 26° NE and 26° SE will receive the light of the rising sun, so this effect may have been planned, or it may have been coincidental. Coyne and Bellier[11] argued that the orientation of the temple was a geologically determined alignment, however, according to Amelia Edwards[12] “it was a calculated effect, and that the excavation was directed at one especial angle in order to produce it”. Haagen[13]

[9] Azimuths sourced from JPL.

[10] Redshift Pro astronomy software, Multimedia astronomy sky mapping multi-platform v. 2/4, Maris Multimedia (hereafter Redshift Pro); Stellarium astronomy software v.0.19.2, F. Chéreau.

[11] A. COYNE, J. BELLIER, *Preliminary design of the structures for the protection of the Abu Simbel temples* 3. *Technical documents. Texts.* 3,1. *Natural conditions*, Paris, 1960, 3, 11.1-2.

[12] A. EDWARDS, *A thousand miles up the Nile*, p. 276.

[13] J. HAAGEN, “Rameses’ mysterious encounter at dawn”, p. 14.

agreed, noting that the temple's 60 m long corridor wasn't perpendicular to the plane of the mount's façade; "the temple seems deliberately to have been constructed on an axis not exactly at right angles to the façade".

Twice a year the Egyptian Government[14] holds the 'Sun Festival' at Abu Simbel, asserting that the central dates of the illuminations (22 October and 22 February) were intended to mark the birth date and coronation date of Ramses II. Hawass[15] rejects this notion: "It has been suggested that this magical event represents the birth and ascension to the throne of Ramesses II, but I believe that this is only an astronomical feature." Helck[16] proposed III *šmw* 27 as his accession date. Brand[17] and Beckerath[18] agree effectively ruling out this rationale for the illuminations.

There was an important festival which occurred during these dates called khoiak. According to the Papyrus Jumilhac (c. 100 BC), proceedings commencing on IV *ꜣḫt* 19 with 'finding the head' of Osiris and on each of the following days another body part was found until proceedings ended on IV *ꜣḫt* 30 with 'finding the arm'.[19] In the more contemporary 'Calendar of Feasts and Offerings' at Medinet Habu (12th century B.C.), proceedings commenced on IV *ꜣḫt* 21 and lasted until IV *ꜣḫt* 30.[20] This calendar largely copied the calendar preserved in Ramses II's Ramesseum.[21] The dates of khoiak preserved in the Papyrus Jumilhac an at Medinet Habu are very close to the range of dates that the statue group at Abu Simbel was illuminated.

There are some architectural elements in the Great Temple which support a link with khoiak. Khoiak re-enacted the death of the god Osiris at the hands of Seth and then celebrated his resurrection at the culmination of the festival. Strong links to this god are found within the Great Temple. The hypostyle hall is lined with eight columns in the form of Osiris. Furthermore, the temple itself is aligned to stars that were associated with this god. Jan van der Haagen and Henri Bonneval[22] calculated that a star in Orion's Belt rose in line with the temple's axis: "for a number of years around 1260 BC, an exceptionally brilliant star in the constellation of Orion did in fact rise in the vicinity of the axis of the temple. … the middle star, the one we are concerned with, bears the Arabic name of Alnilam."

According to the Haagen's[23] communications with the Institut Géographique National, the axis of the temple is 101° to the north. When Alnilam cleared the hills in the 1260's BC, its

14 Egyptian Tourism Authority, *Sun festival at Abu Simbel* <http://egypt.travel/en/attractions/sun-festival-at-abu-simbel> (3 January 2021).
15 Z. HAWASS, *The mysteries of Abu Simbel*, Cairo, 2000, p. 77.
16 W. HELCK, "Bemerkungen zu den thronbesteigungen im Neuen Reich", *Studie Biblica et Orientalia* III, *Analecta Biblica* 12, Rome, 1959, p. 118-120.
17 P. BRAND, *The monuments of Seti I: Epigraphic, historical and art historical analysis*, Leiden, 2000, p. 302-305.
18 J. BECKERATH, *Chronologie des Pharaonischen Ägypten*, Mainz, 1997, p. 108, 190.
19 UCL Petrie Museum digital Egypt database, *Festivals of khoiak*, <http://www.ucl.ac.uk/museums-static/digitalegypt/ideology/khoiak.html> (03 May 2019).
20 UCL Petrie Museum digital Egypt database, *Festivals of khoiak*, <http://www.ucl.ac.uk/museums-static/digitalegypt/ideology/khoiak.html> (03 May 2019).
21 R.A. PARKER, *The calendars of Ancient Egypt*, *Studies in ancient oriental civilization, No. 26,* Chicago, 1950, p. 40.
22 J. HAAGEN, "Rameses' mysterious encounter at dawn", p. 14-15.
23 J. HAAGEN, "In Aboe Simbel werd het Heb-Sed gevierd voor Ramses II", *Elseviers Maandblad De Kern* 40, Amsterdam, 1962, p. 35.

apparent azimuth was 100.4°, however, it would not have been visible at that altitude.[24] Atmospheric extinction veils stars when they are close to the horizon. The brighter the star, the closer it can be detected to the horizon. According to Schaefer[25]: "At some angle above the horizon (the extinction angle), the starlight will dim to invisibility. … For an extinction coefficient of 0.25 magnitude per airmass (a clear sky), the extinction angle is 1.5°, 2.0°, 2.8°, 4.2°, 6.6° and 13.5° for stars of 0, 1, 2, 3, 4 and 5 magnitude brightness."

Alnilam is a second magnitude star, so it would become visible to the naked eye at an elevation of ~2.8°. When Alnilam had an apparent elevation of 2.8° in 1260 BC at Abu Simbel, its azimuth was 101.075°; and when Alnilam had a geometric elevation of 2.8°, its azimuth was 100.98°.[26] This star was indeed directly aligned with the axis of the temple. Futhermore, when Alnilam was in this position, another Belt star 'Mintaka' was at an elevation of 4.18° and carried an almost identical azimuth, thus forming a near vertical line in the skies which marked the axis-line of the temple.[27]

Very few Ancient Egyptian constellations have been identified with certainty. In the Middle Kingdom decan lists, 36 constellations were typically recorded, but only Orion and Sirius have successfully been identified.[28] In the fifteenth century B.C., the astronomical ceiling of Senenmut was painted depicting the decan list and a series of constellations. On the southern side of the ceiling (corresponding to the southern skies), two constellations are known: Isis representing Sothis (which includes Sirius) and Osiris representing Orion.[29] Osiris' constellation is one of the few that we know of with certainty from Ancient Egypt. It matches at least a portion of the modern Orion constellation. The Orion constellation is centred around 3 stars which create a distinctive line in the skies. These are known as Orion's belt. Above the depiction of Osiris' constellation in Senenmut's tomb are three stars which many identify with the Belt stars.[30]

The alignment of the Great Temple to the Belt stars, as well as the presence of Osirid columns lining the entrance to the temple, are strong indications that this temple was linked to Osiris. Furthermore, that the dates of illumination match the dates of khoiak, which is a festival celebrating the death and resurrection of Osiris, is a strong indication that this temple was related to khoiak. Other theories on its purpose have been proposed. According to Kitchen[31] the Great Temple was a memorial temple designed to link the solar cult to the royal cult. Christophe[32] argued that the temple was about the king's Heb Sed. According to Ramzy[33] "the

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[24] Azimuth sourced from Redshift Pro. Note that I am using the year 1260 BC, although these values apply for the entirety of the 1260's BC. 100.4° is Alnilam's apparent elevation.

[25] B.E. SCHAEFER, "The latitude and epoch for the formation of the southern Greek constellations", *JHA* 33/4, 2002, p. 320.

[26] Coordinates sourced from Redshift Pro. It is unclear which value was intended by Bonneval and Haagen, apparent or geometric, although only 0.1° separates the two observations. When Alnilam had a geometric elevation of 2.8°, its azimuth was 100.98°.

[27] Coordinates sourced from Redshift Pro. The azimuth of Mintaka was 0.033° less than Alnilam's and the azimuth of the third bright star in Orion's Belt (Alnitak) was only 0.1° less than Mintaka's.

[28] O. NEUGEBAUER, *The exact sciences in antiquity*, New York, 1957, p. 82-83.

[29] R.A. PARKER, "Ancient Egyptian astronomy", *PTRS* 276, 1974, p. 59.

[30] V. TRIMBLE, "Astronomical investigation concerning the so-called air-shafts of Cheops' pyramid", *MIO* 10, 1964, p. 183; S. SYMONS, "Ancient Egyptian astronomy: Timekeeping and cosmography in the New Kingdom", PhD Thesis, University of Leicester, 1999, p. 196; G. PRISKIN, "The constellations of the Egyptian astronomical diagrams", *ENiM* 12, 2019, p. 154.

[31] K.A. KITCHEN, *Pharaoh triumphant: The life and times of Ramesses II*, Cairo, 1997, p. 252.

[32] L. CHRISTOPHE, *Abou-Simbel at l'épopée de sa découverte*, Brussels 1965, ch. 8.

phenomenon may have been considered as a "divine" starting sign from the god/Pharaoh for the beginning of planting and harvest season." The temple also contains detailed accounts of the Battle of Kadesh making it a commemoration of that battle, while the incredible size of the temple also served as a warning to the Nubians of the might of the Egyptians.[34]

It is not the intention of this article to discount any of these theories, it is simply to highlight another aspect of the temple's design, namely, its relation to khoiak.

Was khoiak fixed to the civil calendar, or to the natural seasons?

The major issue that this hypothesis encounters is that of the civil calendar, which wandered away from the solar year at a rate of one day every four years. Winlock[35] argued that the festivals were governed by this calendar:

> In modern studies on the historic Egyptian calendar one sometimes reads of a 'civil' or 'wandering year' and of a co-existent 'fixed year' by which festivals might be kept in unvarying relation to the more or less true solar seasons… the ancient Egyptians, from the Old Kingdom to the Roman Period, have not left a single trace of such a fixed calendar. Out of the thousands which have survived from dynastic Egypt, not one document gives equivalent dates in the known 'wandering' year and the hypothetical 'fixed year'.

If Winlock was correct, then the festivals followed the civil calendar, in which case, khoiak would have been dragged away from its original placement in the year. When the civil calendar was first constructed, it is likely that the seasons were in harmony with the natural year[36] and this planting festival would have filled the final days of *ꜣḫt*, the season of the inundation. This was the ideal time for the Ancient Egyptians to plant their crops, for the receding waters left the arable land soft and easy to plant. If the civil calendar governed khoiak's placement, then as the calendar shifted away from the natural seasons, it would have dragged khoiak with it.

Sowing and harvest festivals could only move so far before they would be impeded by the annual flood, consequently, Gatterer[37] proposed a fixed year running independently of the civil calendar. Lepsius[38], Brugsch[39], and Sethe[40] agreed that a fixed calendar was necessary to keep these feasts in their correct place in the year.

Parker[41] disputed such a fixed year and instead proposed a lunar calendar to counter the problem of agricultural feasts losing their optimal seasonal placement, however, it is not the

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[33] N. RAMZY, "The genius loci at the Great Temple of Abu Simbel", *JAHA* 2/2, 2015, p. 47.
[34] L. DOSS, A. BESADA, *The story of Abu Simbel*, Essex, 1973, p. 29, 44.
[35] H.E. WINLOCK, *The origin of the Ancient Egyptian calendar*, Proceedings of the APS 83/3, Philadelphia, 1940, p. 152.
[36] E. MEYER, *Aegyptische chronologie*, Berlin, 1904, p. 11-14.
[37] J.C. GATTERER, *Commentationes de theogonia Aegypt*, *Commentationes Societatis Regiae Scientiarum Gottingensis Historicae et Philologicae Classis* VII, Gottingen, 1786, p. 34, 49-52.
[38] R. LEPSIUS, *Die chronologie der Aegypter. Einleitung und erster theil kritik der quellen*, Berlin, 1849, p. 149-158.
[39] H.K. BRUGSCH, *Die Aegyptologie*, Leipzig, 1891, p. 353.
[40] K. SETHE, *Die zeitrechnung der alten Aegypter im verhältnis zu der anderen völker*, Chicago, 1919-1920, p. 300-302.
[41] R.A. PARKER, *The calendars of Ancient Egypt*, *Studies in ancient oriental civilization*, p. 37-50.

purpose of this article to tackle the issue of a lunar calendar, simply to show that the civil calendar could not govern the timing of important agricultural festivals (thus enabling Abu Simbel to mark khoiak with its illuminations).

If the civil calendar had controlled the placement of khoiak, then the dates of illumination of the Great Temple would only have coincided with the dates of khoiak in an ideal year (i.e. when the civil calendar was in harmony with the natural seasons). This only occurred once in every 1,460 years. The civil calendar estimated the length of the year to be 365 days, whereas the true solar year is a quarter day longer. Consequently, the civil year wandered from the solar year at the rate of one day per four years. Winlock[42] estimated that the civil calendar coincided with the realities of the seasons in the year 1317 B.C. Parker[43] estimated 1313 BC. According to Kitchen[44] Ramses II's coronation occurred in the year 1279 B.C and he ruled until 1213 B.C. At the start of his reign the civil calendar was about 9 days ahead of the natural seasons; by the end of this reign it was 26 days ahead. If khoiak was governed by the civil calendar, then the illuminations at Abu Simbel did not coincide with this festival by the time Ramses built this temple.

Khoiak was ultimately a planting festival wherein the death of the corn god Osiris led to the internment of corn dolls in the fields. These rites accompanied the planting of the corn crop throughout Egypt. When Herodotus[45] visited Egypt in the fifth century B.C. he made the following observation about the corn planting:

> At present, it must be confessed, they obtain the fruits of the field with less trouble than any other people in the world, the rest of the Egyptians included, since they have no need to break up the ground with the plough, nor to use the hoe, nor to do any of the work which the rest of mankind find necessary if they are to get a crop; but the husbandman waits till the river has of its own accord spread itself over the fields and withdrawn again to its bed, and then sows his plot of ground, and after sowing turns his swine into it – the swine tread in the corn – after which he has only to await the harvest.

The synchronisation of the calendar with the seasons occurred c. 1315 B.C. According to Sansone[46] Herodotus wrote 'The History' c.425 BC, which means that ~890 years had elapsed since synchronisation. By this stage, the calendar was ~223 days off reality (i.e. 890 ÷ 4 = 222.5). If the civil calendar was followed, khoiak would have filled the dates I *šmw* 12–21, however, according to Herodotus' account, the planting rites were not governed by the calendar, for he observed the Egyptians planting the corn when the waters of the Nile abated.

GDU's

Further evidence that the planting festival could not have been determined by the civil calendar is provided by the number of sunlight hours that a corn crop requires to mature. Corn follows a predictable growing pattern which is determined by the amount of heat that it

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42 H.E. WINLOCK, *The Origin of the Ancient Egyptian Calendar*, p. 152.
43 R.A. PARKER, *The calendars of Ancient Egypt*, *Studies in Ancient oriental civilization*, p. 39.
44 K.A. KITCHEN, "Pharaoh Ramesses II and his times", in J.M. Sasson (ed.) *Civilizations of the Ancient Near East*, New York, 1995, p. 763, 770.
45 HERODOTUS, *The history*, G. Rawlinson (trans.), Hertfordshire, 1996, II.14, p. 122.
46 D. SANSONE, "The date of Herodotus' publication", *Illinois Classical Studies* 10/1, 1985, p. 8-9.

receives. Corn follows the formula: (daily maximum temperature + daily minimum temperature ÷ 2) - 50°F.[47]

Table 1 presents the number of GDU's that the corn would receive in an average year for the months March to June.

	Max. temperature (°F)	Min. temperature (°F)	GDUs per day
March	73	54	13.5
April	82	59	20.5
May	89	64	26.5
June	93	70	31.5

Table 1. Average monthly temperatures from Cairo with the associated number of GDU's, using observations derived from *Weatherbase* (2021).[48]

If the crop was planted according to the civil calendar in 425 B.C., the maximum amount of time that the corn could be in the ground would be limited by the arrival date of the flood. According to Diodorus[49] the flood was due to arrive at the summer solstice:

> The rise of the Nile is a phenomenon which appears wonderful enough to those who have witnessed it, but to those who have only heard of it, quite incredible. For while all other rivers begin to fall at the Summer solstice and grow steadily lower and lower during the course of the following Summer, this one alone begins to rise at that time and increases so greatly in volume day by day that it finally overflows practically all Egypt.

The flood was due to arrive at the summer solstice, which was I *ꜣḫt* 1 according to the civil calendar when the calendar was in harmony with the natural seasons. This was the terminus date for the harvest. Planting at khoiak as reckoned by the civil calendar in 425 B.C. (i.e. I *šmw* 12) would leave 114 days for the crop to mature:

I *šmw* = 19 days

II *šmw* = 30 days

III *šmw* = 30 days

IV *šmw* =30 days

[47] UNL Institute of Agricultural and Natural Resources, *Cropwatch*. <https://cropwatch.unl.edu/growing-degree-units-and-corn-emergence> (01 February 2021). Note that the maximum temperature is set to 86°F (anything above that value is set to 86°F) and the minimum temperature set to 50°F.

[48] Weatherbase database: <http://www.weatherbase.com/weather/weather.php3?s=66326&cityname=Cairo%2C+Muhafazat+al+Qahirah%2C+Egypt> (29 June 2019).

[49] DIODORUS, *Library of history*, C. Oldfather (trans.), Cambridge, MA, 1933, I.36, p. 125.

Epagomenal = 5 days

In the Northern Hemisphere the summer solstice occurs when the sun's path is farthest north in the skies and this occurred on June 24 (Gregorian). This date is not included in the calculations as it was the anticipated arrival date for the flood (although its actual arrival date was erratic). The equivalent modern Gregorian dates to te 114 days listed above are 2 Mar - 23 June. Listed below are the associated number of GDU's accrued in that time:

March GDU's: 30 days x 13.5 = 405 units

April GDU's: 30 days x 20.5 = 615 units

May GDU's: 31 days x 26.5 = 821.5 units

June GDU's: 23 days x 31.5 = 724.5 units

Total GDU's: = 2566 units

A crop planted according to the civil calendar's placement of the khoiak festival in Herodotus' time would only receive ~2,566 GDU's. According to the UK College of Agriculture[50], a modern crop requires between 2,700 and 3,100 GDU's to mature. The crop would not get enough sunlight to mature before the summer solstice.[51] A century and a half after Herodotus, the GDU's would be down to 2,000, which is well below requirements.

Herodotus' observation, and insufficient sunlight hours, demonstrate that khoiak could not have followed the civil calendar. The planting rites which this festival governed had to follow nature's calendar (i.e., the receding Nile) or else crop failure would ensue. Consequently, the illuminations of the Great Temple did coincide with khoiak.

Refining the dates of illumination

The dates of khoiak recorded in the Papyrus Jumilhac were 11–22 October, and those recorded in Medinet Habu were 13–22 October. The dates of illumination were 13–22 October in 1959, which is equivalent to 12–21 October in the 13th century B.C. If these illuminations were to be extended by one day, it would mean that the final day of khoiak would be included. This was a particularly important date that was marked by the raising of the Djed pillar in both the Medinet Habu calendar and the Papyrus Jumilhac.[52]

In 2017 I visited the Great Temple to see whether the dates of illuminations continued on into October 23 (equivalent to October 22 in Ramses' time). On October 23, a portion of the face of Ramses' statue as well as the left side of his body was illuminated by the rising sun [fig. 2].

[50] UK College of Agriculture, *Corn growth stages and growing degree days* <https://www.ifao.egnet.net/uploads/publications/normes/IFAO_publications_normes_bibliographiques_pub_egypto_2020_angl.pdf> (08 January 2021).

[51] Note that this is without taking into account the fact that the harvest takes time, nor is it taking into account the erratic nature of the inundation which was known to arrive early; for example, in one year, Parker noted that the waters of the Nile began to rise in mid-April; see R.A. PARKER, *The calendars of Ancient Egypt*, *Studies in ancient oriental civilization*, p. 32, n. 21.

[52] UCL Petrie Museum digital Egypt database, *Festivals of khoiak*, <http://www.ucl.ac.uk/museums-static/digitalegypt/ideology/khoiak.html> (03 May 2019).

This statue and the statue of Amun-Ra sit either side of the central axis (which is marked by the plinth). They are framed by the doorway of the inner sanctum and from the exterior of the temple, the view down the corridor is of these two statues. Haagen used the plinth as the viewpoint for his observations because it is centred, however, that the face of the builder is still lit serves to indicate that the illuminations could be interpreted as ongoing (note that on the first days of the illumination, only a portion of Amun-Ra was illuminated).[53]

Altering the viewpoint to the doorway of the inner sanctum extends the end date of illuminations by a day (though it does not affect the start date). This shift in viewpoint enables the dates of illumination to include the raising of the Djed pillar.

Consequently, in the modern era (prior to the move), the final day of illuminations was 23 October and these illuminations restarted in the following year on 19 February. The total number of days in-between (when the sun did not shine in the doorway illuminating either Ramses or Amun-Ra), was 118.

In the thirteenth century B.C. dates shift by one day, so the final day of illuminations was 22 October, then they restarted on 20 February in the following year; the total number of days when the sun did not shine in the doorway illuminating either Ramses or Amun-Ra was 120. This is a significant number. The Ancient Egyptian civil calendar divided the year into three seasons of 120 days each, with five so-called 'epagomenal' days added in-between *šmw* and *ꜣḫt*. The length of time between illuminations at Ramses' temple was therefore the same length as one complete season.

The Ancient Egyptian civil calendar calculated the year as 365 days long, when in fact, it is ~365 ¼. Consequently, it fell out of step at the rate of one day every four years. However, for a brief four-year period, occurring once in every 1,460 years, the calendar was in harmony with the natural seasons.[54] In such an ideal year, the season of *prt* would have coincided exactly with this 120-day gap between the illuminations of Ramses' temple. In other words: the final day of illuminations in October would have coincided with the final day of *ꜣḫt*; the season of *prt* would immediately follow, coinciding with the 120-day gap in illuminations; then the temple would be illuminated once more on the first day of the season *šmw*.

Once the calendar began to wander from the seasons, this gap in illuminations would have preserved the dates of the *prt* season in the same position as it was when the civil calendar was first created, and would have done so for the remainder of the Egyptian Empire (whereas the civil calendar would have to wait 1,460 years before returning *prt* to the correct dates).

Altering the viewpoint used in Haagen's observations enabled 22 October to be included (as well as 11 October). This shift in viewpoint is justified by first hand observation, wherein a portion of the statue of King Ramses was illuminated on 23 October in 2017 (equivalent to 22 October in the 13th century B.C.). This extended the range of illuminations by two days (one day at the start and one day at the end) so that they included the final day of khoiak festivities (which included the raising of the Djed pillar) and consequently, the end date of the illuminations coincided with the end dates of khoiak recorded in the Medinet Habu and Papyrus Jumilhac calendars. Furthermore, the entire span of illuminations matched the dates of khoiak preserved in the Papyrus Jumilhac calendar. This extension of the illumination dates

[53] Footage of the illumination on 23 October was recorded by the author and can be seen on YouTube: "Dawn illumination of Ramses II's temple at Abu Simbel, 23 October, 2017" (https://youtu.be/PR4bX3vAq-0).
[54] H.E. WINLOCK, *The origin of the Ancient Egyptian calendar*, p. 148.

also meant that the end date in October and the restart date in February coincided with the turning of the seasons. The illuminations ended on the final day of *ꜣ ḫt* (in an ideal year); the following day was the first day of *prt*. Likewise, the illuminations restarted when *prt* ended, marking the first day of *šmw*. According to Maravelia and Shaltout[55] "it would be plausible to assume that the phenomenon of illumination occurring on them was used as a practical astronomical harbinger of these ancient Egyptian seasons". Also, Belmonte, Shaltout and Fekri[56] argued that the illuminations were designed to signal the start of *prt* and *šmw*.

The starting date for the illuminations may have been controlled by a door. The Medinet Habu calendar is more likely to have been followed in Ramses II's time, rather than the Papyrus Jumilhac. According to that calendar, the khoiak proceedings commenced with the opening of the window in the Shetayt shrine on IV *ꜣḫt* 21.[57] A door may have been used at Abu Simbel to commence the illuminations on this date, with the closing of the door on IV *ꜣḫt* 30 to end them.

Conclusion

When Haagen's viewpoint is altered from the central plinth, to the doorway of the inner sanctum, the illuminations of the Great Temple at Abu Simbel are shown to have lasted for 12 consecutive days in October and coincided with the khoiak festival in its correct placement in the natural year (i.e. the final days of *ꜣḫt*). While the civil calendar did wander away from the natural seasons, this article has demonstrated that it was not possible for this planting festival to have wandered with the calendar, as this would have led to crop failure by the time of Herodotus. Furthermore, the illuminations ended on the final date of the flood season *ꜣḫt* and recommenced on the first day of the harvest season *šmw*, so effectively, the Great Temple was a calendar which illuminated to signal planting time, stopped illuminating for the length of the season *prt*, then re-illuminated to signal the start of *šmw*. The illuminations in the Grat Temple preserved these dates accurately for the remainder of the Egyptian Empire.

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[55] A. MARAVELIA, M. SHALTOUT, "Illumination of the sacrarium in the Great Temple at Abu Simbel, its astronomical explanation, and some hints on the possible stellar orientation of the Small Temple", dans A. Maravelia (ed.), *European archaeoastronomy and the orientation of monuments in the Mediterranean basin*, *BAR* S1154, Oxford, 2003, p. 10.

[56] J.A. BELMONTE, M. SHALOUT, M. FEKRI, "Astronomy, landscape and symbolism: a study of the orientation of Ancient Egyptian temples", dans J.A. Belmonte, M. Shaltout (eds.), *In search of cosmic order: Selected essays on Egyptian archaeoastronomy*, Cairo, 2009, p. 230.

[57] UCL Petrie Museum digital Egypt database, *Festivals of khoiak* <http://www.ucl.ac.uk/museums-static/digitalegypt/ideology/khoiak.html> (03 May 2019).

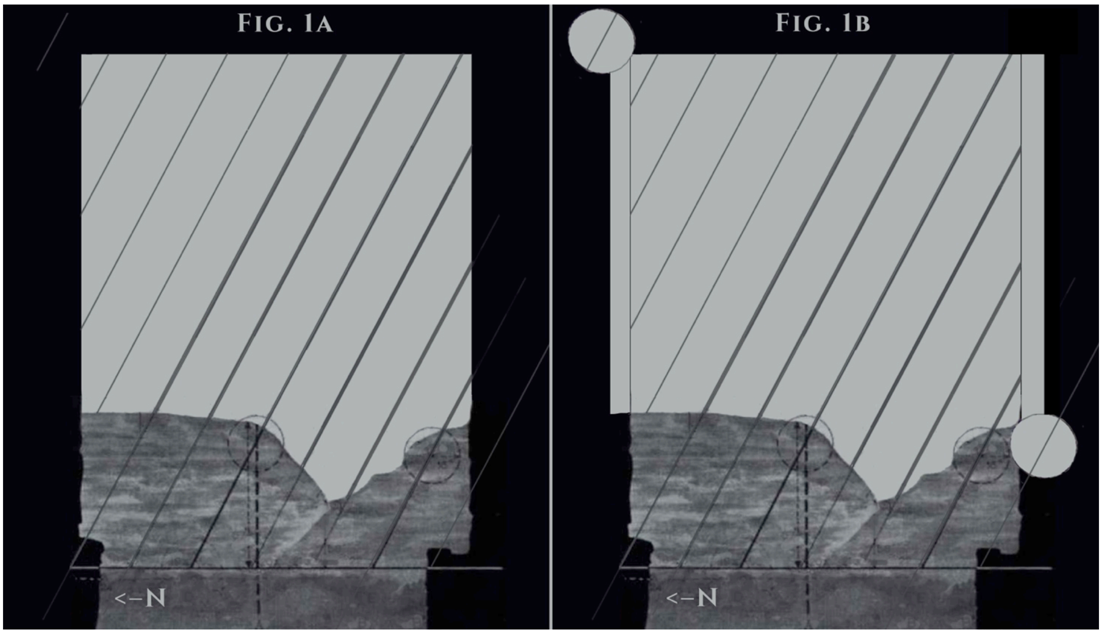

Fig. 1a. Looking eastwards out of the Great Temple with the paths of the sun shown. I have completed Haagen's image to show all the days that the sun rose in line with the doorway as seen from the plinth (the 6 paths by Haagen are in bold). Fig. 1b shows all the paths of the sun when the viewpoint is the doorway of the inner sanctum. (Drawings by the author based on J. Haagen, "In Aboe Simbel werd het Heb-Sed gevierd voor Ramses II", p. 40).

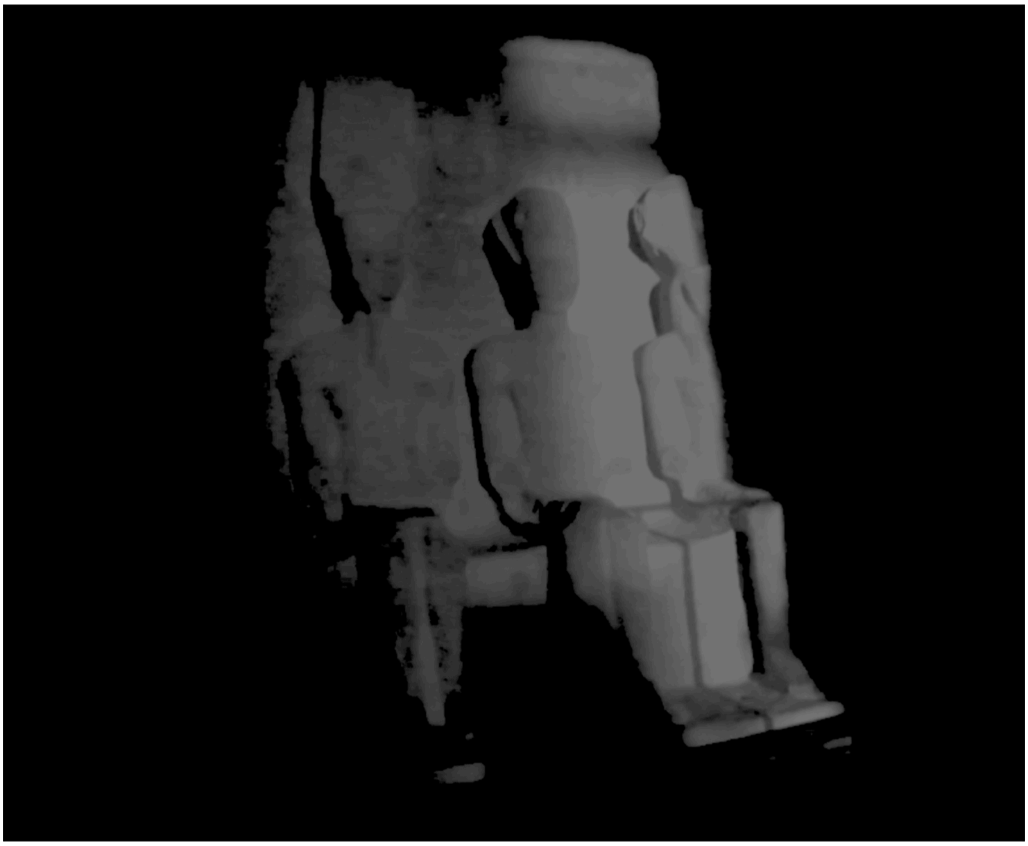

Fig. 2. The sun illuminating the inner sanctum on 23 October, 2017 (photo by the author).