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PRECESSION ISSUES IN POLYNESIAN ARCHAEOASTRONOMY

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Until about the 17th century, nowhere in the world could longitude be determined at sea other than by dead reckoning. Longitude fixing only became practicable, and initially only for European navigators, following advances in instrumentation (primarily the marine chronometer and sextant) and the availability of astronomical data in the late 17th and 18th centuries. In the absence of information on longitude, latitude and azimuth determination were crucial for early Polynesian navigators, in addition to a range of other navigation strategies including the use of swells, birds and techniques to expand landfalls (e.g., Evans 2011: 55-72). Neither latitude nor azimuth could be determined exactly, and extensive use of stars was required for both. For azimuths, complex star compasses have been important throughout Polynesia (Chauvin 2000: 112; Finney 2006: 159-61, 183-84; Lewis 1994: 104, 108, 118; Low 2006: 188). Such compasses relied on detailed knowledge of the movements of a great many stars (Evans 2011: 56; Finney 2006: 162). Good precision was hard to realise, especially at higher latitudes, because stars follow increasingly inclined trajectories and are only useful for a short time after rising (Evans 2011: 64).¹ For determining latitude, the angle of stars above the horizon could be used, gauged roughly by hand-spans or finger-breadths (Low 2006: 191). Latitude could also be determined using zenith stars, or vertical star pairs, or by the simultaneous rising or setting of star pairs (discussed further below). Since dead reckoning to allow for currents and winds was inexact, navigators would sometimes return home after north/south voyages by deliberately aiming too far east or west and then sailing a line of constant latitude (Finney 2006: 169; Lewis 1994: 286-87).² Stars or groups of stars might also have been important as an inspiration for voyages if navigators assumed that prominent stars passed over significant islands (Kyselka 1987: 7-9). Vertical or simultaneously rising pairs of stars that made sailing on a particular latitude easier might also have suggested the presence of islands at that latitude, or at least have made sailing those latitudes more likely, so increasing the likelihood of discovering land.

Given this dependence on stars, it is important to bear in mind that their positions alter gradually over the centuries, with by far the biggest change being due to precession,³ the phenomenon by which the Earth's axis of spin alters relative to the stars over a period of about 25,800 years, like a spinning

top (Ruggles 2015: 473-74). Although there is no shortage of general literature about the effects of precession in archaeoastronomy (e.g., Ruggles 2015: Chapter 31; see also Lusby *et al.* 2010: 15; Magli 2015: 16-19), this article grew out of a need for a better understanding of precession in the context of Polynesian voyaging. Knowledge about the effects of precession can assist scholars in weighting one voyaging date more likely than another, or in providing possible reasons why certain voyages took place in a particular era if navigation methods depended on star configurations that were particularly favourable in that era. Precession has been adduced by Lusby *et al.* (2009: 21) to support an “archaeoastronomical dating method” and the possibility of “sea lanes” on latitudes at which star pillars are vertical, and sailing on the latitude of particular island targets would have been particularly easy (Lusby *et al.* 2010: 16). For example, when Goodwin and colleagues (2014) suggest windows of off-wind (i.e., downwind) sailing from the Central Eastern Pacific to Easter Island as being between AD 800 and 1275 (with AD 1200–1253 being the best colonisation estimate; p. 14717), it may be helpful to note that the star pillar comprising Spica and Antares (setting) formed a more vertical star pillar on the latitude of Easter Island in AD 1275 than it did in 800, by about 20' (or 37 km on the Earth's surface). Also, if the effects of precession were not recognised and accounted for by successive generations of navigators, then the locations of distant known islands, especially those which were small targets, might be “lost”.

The influence of precession on stars used for different methods of latitude determination is not always intuitive, and in this article a graph of the change in declination per century as a function of right ascension is proposed as a way of understanding the influence of precession on different methods of latitude and azimuth determination and of deducing when and where significant configurations occur.

DEFINITIONS

To understand precession, several terms and units need to be defined and explained. Stars are catalogued using two coordinates, namely declination and right ascension, which are illustrated in the inset to Figure 3. Declination (δ) is the equivalent of an observer's latitude on the Earth. In other words, it is the angle to the north or south of the equator on a conceptualised celestial sphere, the centre of which is the Earth, and which for convenience treats stars as having a uniform distance from the Earth. Declination is usually measured in degrees, minutes of arc (which are one sixtieth of a degree) and seconds of arc (which are one sixtieth of a minute of arc). Right ascension, which is equivalent to longitude on the Earth's surface, is measured from an arbitrarily chosen origin on the celestial sphere where the sun appears to cross

the celestial equator going from south to north each year. Modern astronomers name this origin the vernal equinox, and from it, right ascension is measured eastwards in units of hours, minutes of time and seconds of time, where 24 hours is equivalent to 360° of arc, and converting from hours to degrees is a simple matter of decimalising and multiplying by 15. On the Earth, an observer's meridian is the plane containing the observer and true north (as opposed to grid north on a projection, or to magnetic north). On the celestial sphere, the observer's meridian is the great circle containing the observer's zenith (i.e., the point on the sphere directly above the observer), the North Celestial Pole (NCP; i.e., the point where the North Pole projects onto the celestial sphere), and similarly the South Celestial Pole (SCP). The azimuth is the angle of a star (or other heavenly object) measured clockwise (i.e., positive east) in degrees, minutes and seconds of arc from true north. The altitude of a star refers to its angle above the horizon, with zenith distance being the complementary angle (in other words, the angle from the observer's zenith measured down to the star). Both altitude and zenith distance are measured in degrees, minutes and seconds of arc.

DETERMINING LATITUDE

Four methods of non-instrument latitude determination are considered here: first, by the altitude of stars in the meridian; second, by the special case of zenith stars in the meridian; third, by the verticality of star pillars; and fourth, by simultaneously rising or setting stars. The effect of precession on each of the four methods is then discussed, and a graph proposed as a way of understanding and quantifying the effect of precession on latitude.

Latitude by the Altitude of Stars in the Meridian

With suitable tables and instrumentation, it is a relatively simple matter to calculate latitude by measuring the zenith distance of a star in the meridian and adding or subtracting its declination. If a numerical value of declination is unavailable, and in the absence of an instrument capable of measuring angles at sea, the angle above the horizon can be gauged approximately by finger-breadths or extended fingers at arm's length, or by knotted string. Such methods are sufficiently precise for navigators to know when they have reached a particular latitude, such as the one they started out from or have visited previously (Chauvin 2000: 106-7; Lewis 1994: 293; Low 2006: 191). Even in the 20th century, Lewis was told by senior navigators of the Micronesian island of Satawal that the height of the Pole Star is still "judged by eye or by the span of the fingers loosely extended at arm's length", with one hand-span being the measure of one *ey-ass*, equal to about 15° (Lewis 1994: 277). In the Northern Hemisphere, Polaris (or alternative pole stars over the centuries as

precession altered the position of the Earth's pole on the celestial sphere) is a convenient mark because it is always approximately in the meridian and its declination is always approximately 90° , meaning that its altitude above the horizon is a direct measure of latitude. In the Southern Hemisphere, where there is no suitable pole star of sufficient magnitude, the angle of other stars at meridian transit is also a measure of latitude, for example, stars in the Southern Cross when its longer axis is roughly vertical (Thompson 2016: 2). However, the disadvantage of this is that stars will only cross the meridian twice in 24 hours, once at upper transit and once at lower transit.

Latitude by Zenith Stars

Zenith stars, passing overhead of an observer, are a special case of stars in the meridian. In order to pass through the observer's zenith, these stars must have a declination equal to the observer's latitude. For example, today Sirius is a zenith star for Fiji, passing directly overhead of Vanua Levu once in 24 hours. In Polynesia, a zenith star may be known as "the star on top" or "the star that points down to an island, its overhead star" (Lewis 1994: 278-81).

Another dimension to the use of zenith stars is the way in which Polynesian cosmogonies featured stories that linked bright stars, and also groups of stars, with important islands. Star groups may comprise either official constellations or else asterisms, with the latter being stars comprising a subset of constellations or sometimes stars from more than one constellation that have been arbitrarily grouped by societies. Kyselka (1987: 7-9) suggests that significant stars or asterisms may have inspired Pacific explorers to voyage in search of the islands that they were presumed to mark. Lewis writes that for latitudes south of the equator, where the Pole Star is not visible, the most significant means of fixing latitude was "by means of overhead or zenith stars" (Lewis 1994: 277). In theory, zenith stars can be used as a rough yardstick of latitude by estimating whether they pass directly overhead or to the north or south. In practice, Lewis found that by allowing for the rake of the mast it is possible to estimate closeness to the zenith within about a degree of latitude, and with practice this could be improved to about $30'$ where observations are made in good weather from a stable catamaran (Lewis 1994: 288). Although the usefulness of this method is confirmed by Finney (2006: 169), other navigators have expressed a preference for different methods (see below).

Latitude by the Verticality of Star Pillars

The term "star pillars" has been used to describe both single stars and also pairs of stars comprising a near-horizon star and a star vertically above it. For the former use, namely as single stars, Teuira Henry quotes Rua-nui, "a clever old woman" (Henry 1928: 359), who referred to "great twinkling stars in the heavens" as pillars of the sky (361),⁴ and David Lewis (1994:

284) appears to use the term “star pillar” synonymously with (single) zenith stars. In contrast, Lusby *et al.* (2009: 22-23) note that carved pillars were a feature of Tahitian architecture, and these authors explore the possibility of “star pillars” referring to pairs of stars with one star representing the base of an upright pillar and the other its top. Vertical star pillars can be used as an indicator of latitude because they tip up according to how far north or south of their vertical position an observer is, either of which causes one or other of the celestial poles to climb in the sky (see Figs 1 and 2). The verticality of such pillars is influenced by precession as well as alterations in latitude. In other words, star pillars will be vertical at different latitudes in differing centuries owing to precession.

Latitude by Simultaneously Rising or Setting Stars

Latter-day non-instrument navigators such as Nainoa Thompson favour using pairs of simultaneously rising or setting stars (i.e., with similar altitudes) in preference to zenith stars as a gauge for changes in latitude (Chauvin 2000: 111; Low 2006: 190-92). Star pillars and synchronous stars to the east and west of observers are illustrated in the following figures:

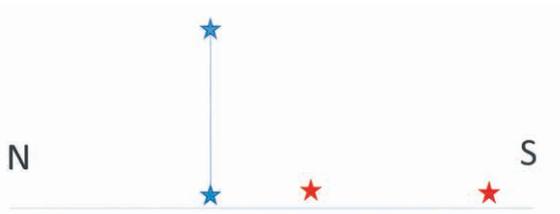


Figure 1. A vertical star pillar and a pair of near-horizon stars viewed to the east (rising).

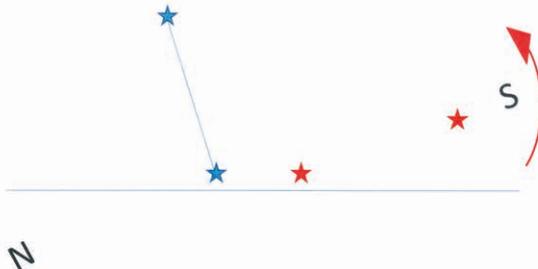


Figure 2. On moving south, the south celestial pole and star pillar will tip up in the sky, and one near-horizon star will rise before the other of the pair. The identical effect may be produced by precession.

THE EFFECTS OF PRECESSION ON MEASURES OF LATITUDE

Precession manifests itself differently for stars in different parts of the sky. In order to convey a feel for the magnitude of changes in celestial coordinates due to precession, between AD 1000 and AD 2000 the declination of Aldebaran increased by about 15' per century, the declination of Antares decreased by about the same amount, and the declination of Polaris increased by about 32' per century. To put this in context, the average human eye can resolve angles of about one minute of arc (Chapman 1983: 135), meaning that in theory the human eye could discern a difference in the position of Polaris in one thirty-second of a century, or about three years. Only changes in declination are considered here because changes in right ascension manifest themselves as small changes in time. Illustrating this with the example of a zenith star that passes over an island in one epoch, an angular change in right ascension of 1' of arc over three years will have the effect of making the star pass over the island four seconds earlier or later at the end of that period, which would be unnoticeable except with sophisticated time-keeping technology. In contrast, changes in declination are independent of time and, depending on where stars are situated in the sky and which of the latitude methods described earlier are being used, these changes may be discernible to the human eye. For instance, the effect of precession on declination can cause a zenith star that passes over an island at one epoch not to do so at another epoch, or it may alter the tilt of star pillars discernibly or affect the synchronicity of simultaneously rising star pairs. Changes in a star's declination per century are easily evaluated using software packages such as SkyMap or Cartes du Ciel (Sky Charts), or else these can be looked up on declination tables such as the one Ruggles (2015: 475-78) gives, which lists the declinations of the 25 brightest stars between 5000 BC and AD 2000.

However, how precession influences the latitude methods described above is not intuitive. For example, it is not readily apparent how much a navigator's latitude needs to change in order to make a star pillar vertical at a different epoch, or to make simultaneously rising stars again rise synchronously. Such calculations may be facilitated by the following graph (Fig. 3) of the change in declination per century plotted against right ascension, between AD 1000 and 2000, the centuries most relevant to East Polynesian colonisation and post-settlement voyaging (Goodwin *et al.* 2014; Kirch 2000: 231). Apart from Arcturus, which is slightly anomalous and would need a more in-depth look at the catalogues used, the result is a reasonably consistent cosine relationship.

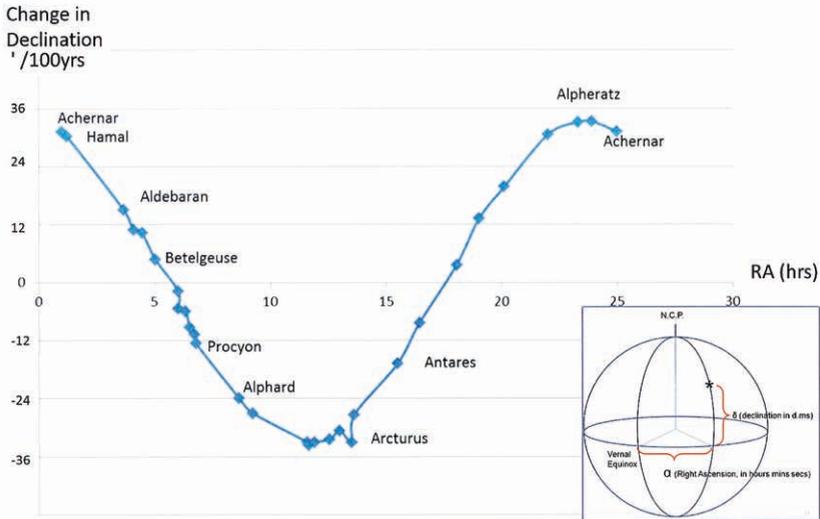


Figure 3. Change in declination with right ascension.

Precession and Star Pillars

How does the graph in Figure 3 help to quantify the effect of precession on a star pillar? Consider for example the star pillar comprising Betelgeuse and Procyon, observed approximately east of an observer (chosen because relationships will become progressively less stable nearer the Poles). From the graph it can be seen that Betelgeuse, the higher star of the pillar, has a right ascension of roughly five hours and its declination changes by about $+5'$ per century (i.e., δ is getting more northerly). Procyon, the lower star of the pillar, has a right ascension of about seven hours and a change in declination of roughly $-13'$ per century (i.e., δ is getting more southerly). Considering Figure 4, the star pillar comprising that star pair has thus in effect twisted anticlockwise, as if the NCP and observer's zenith have migrated anticlockwise.

What we really need to know is how far an observer's zenith has tipped, because the angle between the zenith and the celestial equator is in fact the observer's latitude. To find the rotation of the zenith, we can deduce the right ascension of the observer's zenith from the graph in Figure 3 (because its separation from the horizon will be approximately 90° , or six hours), and using this right ascension we can read from the graph by how much the declination of the observer's zenith (which is in fact the observer's latitude)

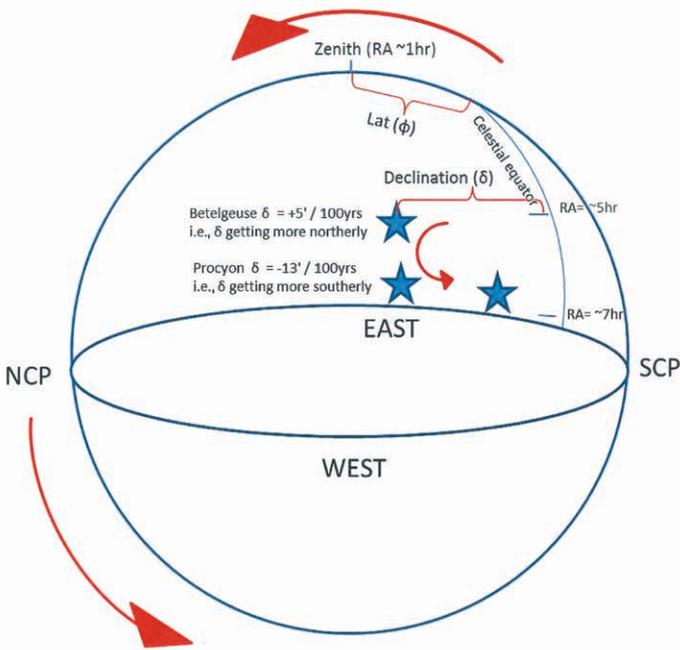


Figure 4. Zenith movement caused by star-pillar twist.

has altered. For this particular pillar, Procyon is the near-horizon star, with a right ascension of roughly seven hours, and the observer is looking east, meaning that the observer's zenith has a right ascension of approximately six hours less than that of Procyon, in other words about one hour. This approximate right ascension permits interpolation of an approximate change in declination of the observer's zenith from the graph in Figure 3, namely about $+34'$ per century. Simply put, the observer's zenith when observing that star pillar will change by about $34'$ in a hundred years, and hence the difference in latitude necessary to counteract that precessional change will be, very approximately, $34'$. Thus a "sea lane" with an upright pillar comprising those stars would now lie further to the north, at a latitude where the NCP has tipped up in the sky and the star pair has rotated clockwise to counteract the effect of precession. This is easily verified: a century later, the star pillar is indeed vertical at a latitude of about $36'$ further north (see the numerical example below).

If the star pillar had been to the west, then the order of stars in the pillar would have been reversed, meaning that a “sea lane” with the inverted star pillar would now lie further to the south. Pillars comprising other stars will change by different amounts depending on their declination, the observer’s latitude, and the separation of the stars forming the pillar. It is not difficult to find examples ranging from 1', 7', 25' and up to about 36' per century, with the sign depending on whether pillars are observed to the east or west. As stated earlier, the average human eye can resolve changes of about one minute of arc, so a precessional change that alters the verticality of a star pillar by about 32' per century will change 1' (and therefore be visible to the human eye) within about three years. In a generation of 25 years, it will change by eight times this. Clearly this has to be borne in mind in any attempt to explain or date voyages using the verticality of star pillars as one evidence strand, as has been done by Lusby *et al.* (2009, 2010).

Numerical examples are given below for east and west pillars. Cartes du Ciel and SkyMap software were used as a check for one another (Cartes du Ciel; SkyMap).

East pillar: From 0° latitude (i.e., the Equator) and longitude 149°34'00"W (this is arbitrary; the longitude could have been anything) on 20 March AD 969 at UT 22:27:13 looking roughly east, Procyon and Betelgeuse form a near-enough vertical pillar. A century later (20 March AD 1069) at UT 22:29:10 the “sea lane” with the same star pillar will be further north, at 36'20"N.

Using the same stars, but forming a west pillar: On 10 September AD 982 at UT 21:23:24 from 3°N and 149°34'00"W, Betelgeuse and Procyon form a vertical pillar when looking west. This pillar will be vertical again a century later (10 September AD 1082; UT 21:25:26) at 36'56" further south (i.e., at 2°23'04"N).

Precession and Simultaneously Rising Stars

Simultaneously rising star pairs selected to be roughly east or west, and at non-extreme latitudes, will have declinations that differ by approximately the angular separation of the stars. They will also have similar right ascensions to one another (because in order to rise or set simultaneously, stars have to occupy approximately the same meridian). Since we have shown that changes in declination due to precession is a function of right ascension, we can conclude that the change in declination per century of both stars in a simultaneously rising pair will be more or less the same. Greater variations will occur for more widely separated stars and higher latitudes. As with the star pillar scenarios, the observer’s zenith will be about six hours different in right ascension from synchronously rising star pairs, and again, as the declination of the zenith changes over the centuries as a result of precession,

so too will one or other of the synchronous stars appear to rise earlier. Once again, the graph in Figure 3 can be used to calculate how far north or south to move in order to make the stars again rise simultaneously.

The foregoing can be illustrated with an example from Ra'iātea in the Society Islands ($16^{\circ}58'50''\text{S}$, $151^{\circ}21'30''\text{W}$). On the day of 5 November AD 1100 at local time 20:21:46, the synchronous star pair of Sirius (α Canis Majoris) and Adara (ϵ Canis Majoris) will rise roughly simultaneously. The azimuth of both stars is within 30° of east (106° and 119° respectively). On the same date, altering the latitude by 10° N causes Sirius to rise first and to be at altitude $2^{\circ}15'36''$ when Adara is rising. At 10° S, Adara rises first and is at altitude $2^{\circ}03'42''$ when Sirius rises. At that epoch from latitudes north or south of this, the stars will not rise simultaneously. Importantly, precession has an identical effect over a long period. To work out at what latitude the star pair is synchronous in the year AD 1650, for example, given that the above stars again have a right ascension of approximately six hours, the observer's zenith will have a right ascension of about 0^{h} (i.e., 90° different). The graph in Figure 3 tells us that for 0^{h} , the change in declination per century is about $35'$ of arc. Thus, in AD 1650 the change in the declination of the observer's zenith will have been about 5.5 centuries $\times 35' = 3^{\circ}12'30''$ (approximately). The observer's zenith has moved north, so an observer 5.5 centuries later will need to sail north in order to tip the North Celestial Pole up in the sky and effectively to move the zenith south again; $3^{\circ}12'30''$ to the north of $16^{\circ}58'50''\text{S}$ is a latitude of $13^{\circ}46'20''\text{S}$. Thus, as we would expect, on the same date in AD 1650 and at $13^{\circ}46'20''\text{S}$ and a time of 21:14:39, the star pair is again roughly synchronous.

Precession and Stars in the Observer's Meridian Including Zenith Stars

Excluding stars near the poles for which even a small movement of the Earth's axis can result in a large change in right ascension, for other stars observed in the meridian, the observer's zenith will have the same right ascension as the stars (i.e., they are both in a meridian with the same right ascension). The observer's zenith will therefore have the same change in declination per century as stars transiting the meridian. This means that an observer's latitude will have to change by the same value as a star's declination in order for the star to maintain the same altitude above the horizon.

For example, from a location in the far north of New Zealand in the year AD 1100, the star Fomalhaut, with declination $34^{\circ}13'$ and right ascension $22^{\text{h}} 7^{\text{m}}$, is directly overhead. From the graph in Figure 3, the change in declination is about $31'$ per century. Thus, in AD 1600, five centuries later, Fomalhaut would no longer be directly overhead from this position. Rather, an observer would have to be approximately 290 km further north or at approximately $31^{\circ}38'$ latitude (calculated from $5 \times 31' = 2^{\circ}35'$) in order for Fomalhaut to be observed directly overhead.

AZIMUTH CHANGES IN EX-MERIDIAN STARS AND ASTERISMS

This final section moves on from latitude determination to consider the effect of precession on single stars and asterisms used for determining azimuth. An important distinction needs to be made between azimuths derived from stars (in which case precession will automatically be a factor) and azimuths based on bird migration paths. An example of the latter is when David Lewis was told in 1966 of a tradition in the Solomon Islands of islanders deducing the presence of a previously unknown island by the behaviour of birds, and following their flight path to discover and settle that land (Lewis 1994: 215). Although such a migration path ought to be independent of precession, stars can be used as a bridging mechanism for flight paths, as confirmed by Lewis when he writes, “The direction of the birds’ flight would be perceived in star compass or analogous terms” (Lewis 1994: 215). In other words, even if “following a bird migration path” is cited as the means of orienting a voyage, stars are likely to have been used in the day-to-day navigation, in which case precession will have been a factor.

Take for example a bar-tailed godwit (*Limosa lapponica*) approaching the great navigation temple or *marae* of Taputapuātea on Ra‘iātea (Society Islands) on a direct line from the Matariki constellation in the evening early in November of the late 13th century AD (a reasonable colonisation date of New Zealand according to Wilmshurst *et al.* 2008), the time of Matariki.⁵ Although the normal flight path for godwits is further west (Gill *et al.* 2014: 119), they have been observed even further east than the Society Islands,⁶ and passing over Ra‘iātea is plausible. If such a godwit flew on to New Zealand, it would fly in the direction of Māui’s Fishhook (Chauvin 2000: 96), or in other words, towards the tail of Scorpius. If the assumption was made that the godwit was making for distant land, and a voyage was undertaken keeping the Matariki constellation dead astern and Māui’s Fishhook ahead, the North Island of New Zealand—*Te Ika-a-Māui* (Māui’s Fish)—would have presented a forgivingly broad target. From a landfall at, say, Whakatāne, Māui’s Fishhook would now pass directly overhead, and Scorpius would form an elegant bridge connecting the North Island with Ra‘iātea.⁷ From Whakatāne, the Matariki constellation in the northeastern sky would be approximately in line with Ra‘iātea. One corollary is that if voyages were determined by the flight paths of birds alone, azimuths determined from Google Earth or spherical trigonometry would still be true today, and would remain so irrespective of era, but any stars used to create a sailing plan based on a bird migration path would need to have precession taken into account. Thus if orientation is checked today—in archaeological work, for example—then even if orientations were nominally towards places, if stars were involved then allowance would need to be made for the action of precession. To give an idea of the magnitudes involved, the

azimuth of the Pleiades between AD 1300 to the present changes by a little under half a degree per century due to precession. Thus if a meeting house was built in Whakatāne in AD 1300, and was oriented towards Matariki (and so, Ra'īātea), and subsequent meeting houses were built on the same footprint up to the present, seven centuries later,⁸ then the azimuth to Ra'īātea should still be identical (other than for minute tectonic movements) but the azimuth to Matariki would have altered by about three degrees.⁹

CONCLUSIONS

This article has explored precessional changes in the context of latitude and azimuth determination in Polynesian voyaging. A graph of changes in declination as a function of right ascension has been proposed as a way of understanding and quantifying the latitude change necessary to counteract the effects of precession on vertical star pillars, simultaneously rising star pairs, and latitude stars in the meridian, including zenith stars. It has been shown that for an easterly pair of stars, the movement needed over the centuries to keep the pillar vertical or the star pair rising simultaneously is opposite to when the pillar sets in the west. Also, depending on the right ascension of the stars, the magnitude of the change will be anywhere between zero and about 35 minutes of arc per century, both positive and negative. Finally, it has been shown that even in the absence of knowledge of longitude it is theoretically possible for alignments to have been made to distant places by means of the migration paths of some bird species, but if stars or asterisms were employed as navigational aids to these flight paths then precession ought to be factored in as part of any analysis of directions.

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NOTES

1. Northern Hemisphere navigators could find approximate north using the Pole Star, but between AD 1000 and AD 2000 its angular separation from the North Pole altered by about 1° per year. The magnetic compass was used by Europeans from about the 12th century, but the angle between Magnetic North and True North can vary by tens of degrees over long voyages (NOAA 2016), and the compass did not supersede older methods of navigation but rather was used as a bridging device for overcast and misty periods (Marcus 1956: 18). In the same

way, some Micronesian navigators even today only use the magnetic compass as a secondary orientation device to maintain headings between star observations (Gladwin 1970: 155; Lewis 1994: 109-10).

2. Some scholars prefer the term “windward landfall” to “latitude sailing” because in the absence of precise positioning it is prudent for sailing vessels to set a course so as to arrive windward of the objective, turning downwind on reaching the required latitude (Chauvin 2000: 111; Lewis 1994: 286-87).
3. Star coordinates also change due to a phenomenon known as proper motion, but these changes are orders of magnitude smaller than changes due to precession.
4. “The sky is said to have been low down formerly, and propped up from the earth with pillars...” (Henry 1907: fn, p. 102).
5. There is no universally agreed time of Matariki, also known as Makali’i in Hawai’i, Matali’i in Sāmoa, Mataliki in Futuna, Mataiki in the Marquesas, Matari’i in Tahiti and by a variety of similar sounding names even beyond Polynesia (Ruggles 2015: 2236). In Polynesia, it is “the first appearance of the Pleiades in the eastern sky at sunset” (Chauvin 2000: 113), in other words, in November sometime. For New Zealand Māori, Matariki is often its heliacal rising before sunrise (first appearance after a period when it has not been visible), in other words, in late May or early June. Or it may be the first new moon following this, or the first full moon, and there are also other ways of marking the New Year such as the first rising of Rigel (Puaka, Ngāi Tahu/Kāi Tahu; or Puanga elsewhere) (Williams 2013: 7).
6. Robert Gill (personal correspondence, 2015) observed a bar-tailed godwit in breeding plumage on Rangiroa, 400 km further west than the Society Islands, on 14 April 1988. This makes it possible that godwits have flown over or landed on Ra’iātea. Sooty shearwaters (*Puffinus griseus*) are another “long-haul” species that visits Ra’iātea and could have signalled the existence of distant islands (Shaffer *et al.* 2006: 12800). The place of birds in orientation is supported by folklore, for example in the following ancient song recorded by Teuira Henry (1928: 123):

*Above is Te-ao-uri,
Below is Te-ao-tea,
All is encompassed by the birds
As they look towards the east!*

Other examples are found in Stimson’s (1957: 73) interpretations of oral literature, such as the “sea road of the Black-heron”.

7. The “claws” of Scorpius extend a little further north than Ra’iātea (which has a latitude of about 17° S), and the furthest southern extent of the tail is 42° S (for comparison, Kaikōura has a latitude of about 42° S, and Cape Rēinga about 34° S).
8. Whether or not this has ever happened remains speculative. Michael Linzey (2004: 16) states that “the ridge pole also points to Hawaiki and New Zealand (as directions in front and behind in cosmological space)”, and Amoamo *et al.* (1984: 27) emphasise the symbolic significance of directing the *tāhu* ‘ridgepole’ towards the sea and Hawaiki. However, on a more literal, less conceptual level,

at present there is as yet no proof that structures were in fact oriented in this way, and initial findings show that pragmatism was evident in the way that meeting houses were oriented in sympathy with confined land sections, and orientation preferences also needed to be balanced with competing customs such as welcoming (Goodwin 2013).

9. For locations elsewhere in New Zealand, the azimuth to Ra‘iātea diverges about 5° in the one direction (for Paihia) and a degree and a half the opposite way (for Cape Saunders).

REFERENCES

- Amoamo, T., T. Tupene and R. Neich, 1984. The complementarity of history and art in Tūtāmure meeting-house, Ōmarumutu Marae, Ōpōtiki. *Journal of the Polynesian Society* 93 (1): 5-37.
- Cartes du Ciel. Copyright © 2006, Patrick Chevalley. Version 3.1. <http://www.ap-i.net/skychart/en/start>
- Chapman, Allan, 1983. The accuracy of angular measuring instruments used in astronomy between 1500 and 1850. *Journal for the History of Astronomy* 14 (2): 133-37.
- Chauvin, Michael E., 2000. Useful and conceptual astronomy in ancient Hawaii. In H. Selin (ed.), *Astronomy Across Cultures: The History of Non-Western Astronomy*. Vol. 1. Dordrecht, Boston, London: Kluwer Academic Publishers, pp. 91-125.
- Evans, Jeff, 2011. *Polynesian Navigation and the Discovery of New Zealand*. Auckland: Oratia Media. [1st ed. 1998].
- Finney, Ben, 2006. Traditional navigation. In K.R. Howe (ed.), *Vaka Moana: Voyages of the Ancestors*. Honolulu: University of Hawai‘i Press, pp. 154-85.
- Gill, R.E., D.C. Douglas, C.M. Handel, T.L. Tibbitts, G. Hufford and T. Piersma, 2014. Hemispheric-scale wind selection facilitates bar-tailed godwit circum-migration of the Pacific. *Animal Behaviour*, 90: 117-30.
- Gill, Robert, 2015. Personal correspondence. E-mail 7/2/2015.
- Gladwin, Thomas, 1970. *East Is a Big Bird: Navigation and Logic on Puluwat Atoll*. Cambridge, MA: Harvard University Press.
- Goodwin, David P., 2013. Aligning the ancestors: The orientation of meeting houses in New Zealand. *New Zealand Surveyor* (302): 13-20.
- Goodwin, Ian D., Stuart A. Browning and Atholl J. Anderson, 2014. Climate windows for Polynesian voyaging to New Zealand and Easter Island. *Proceedings of the National Academy of Sciences* 111 (41): 14716-21.
- Henry, Teuira, 1907. Tahitian astronomy: Birth of the heavenly bodies. *Journal of the Polynesian Society* 16 (2): 101-4.
- 1928. *Ancient Tahiti: Based on Material Recorded by J.M. Orsmond*. Bernice P. Bishop Museum Bulletin 48. Honolulu.
- Kirch, Patrick V., 2000. *On the Road of the Winds: An Archaeological History of the Pacific Islands before European Contact*. Berkeley: University of California Press.
- Kyselka, Will, 1987. *An Ocean in Mind*. Honolulu: University of Hawai‘i Press.
- Lewis, David, 1994. *We, the Navigators: The Ancient Art of Landfinding in the Pacific*. University of Hawai‘i Press. [Reprint of 1972 edition].

- Linzey, Michael, 2004. On the pointing signification of the meeting house. *Fabrications: The Journal of the Society of Architectural Historians* [Australia and New Zealand] 14: 1-2, 13-20.
- Low, Sam, 2006. Nainoa Thompson's path to knowledge: How *Hōkūle'a*'s Navigator finds his way. In K.R. Howe (ed.), *Vaka Moana: Voyages of the Ancestors*. Honolulu: University of Hawai'i Press, pp. 186-97.
- Lusby, Stan, Robert Hannah and Peter Knight, 2009. Navigation and discovery in the Polynesian oceanic empire – Part One. *Hydrographic Journal* 131 & 132: 17-25.
- 2010. Navigation and discovery in the Polynesian oceanic empire – Part Two. *Hydrographic Journal* 134: 15-25.
- Magli, Giulio, 2015. *Archaeoastronomy: Introduction to the Science of Stars and Stones*. New York: Springer.
- Marcus, G.J., 1956. The mariner's compass: Its influence upon navigation in the later Middle Ages. *History* 41 (141-143): 16-24.
- NOAA National Oceanic and Atmospheric Administration, Historical Magnetic Declination. http://maps.ngdc.noaa.gov/viewers/historical_declination/ Retrieved 17/11/2016.
- Ruggles, Clive L. (ed.), 2015. *Handbook of Archaeoastronomy and Ethnoastronomy*. New York: Springer.
- Shaffer, S.A., Y. Tremblay, H. Weimerskirch, D. Scott, D.R. Thompson, P.M. Sagar, H. Moller, G.A. Taylor, D.G. Foley, B.A. Block and D.P. Costa, 2006. Migratory shearwaters integrate oceanic resources across the Pacific Ocean in an endless summer. *Proceedings of the National Academy of Sciences* 103 (34): 12799-802.
- SkyMap Pro 11. Copyright © Chris Marriot 1992-2014.
- Stimson, Frank J., 1957. *Songs and Tales of the Sea Kings*. Salem: Peabody Museum of Salem.
- Thompson, Nainoa. Hawaiian Voyaging Traditions. On Wayfinding. http://pvs.kcc.hawaii.edu/ike/hookele/on_wayfinding.html. Accessed 15/11/2016.
- Williams, Jim, 2013. Puaka and Matariki: The Māori New Year. *Journal of the Polynesian Society* 122 (1): 7-20.
- Wilmshurst, Janet M., *et al.*, 2008. Dating the late prehistoric dispersal of Polynesians to New Zealand using the commensal Pacific rat. *Proceedings of the National Academy of Sciences* 105 (22): 7676-80.

ABSTRACT

Latitude and azimuth determination were crucial for Polynesian navigators, supplemented by techniques such as observations of swells, birds and expanded landfalls. Longitude could only be determined by dead reckoning. Both latitude and azimuth made extensive use of stars, which alter gradually over the centuries due to precession, the movement in the Earth's axis of spin. Knowledge about the effects of precession can assist scholars in weighting one voyaging date higher than another, or in providing possible reasons why certain voyages took place in a particular era if navigation methods depended on star configurations that were particularly favourable in that era. The influence of precession on stars used for different methods of latitude

determination is not intuitive. In this article a graph of the change in declination per century as a function of right ascension is proposed as a way of understanding the influence of precession on different methods of latitude and azimuth determination, and of deducing when and where significant configurations occur.

Keywords: Polynesian navigation, archaeoastronomy, zenith stars, star pillars, star compass, precession

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