THE DARIAN, UTOPIAN, AND ZUBRIN CALENDARS AND SEASONAL DISSONANCE (PART THREE)

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ABSTRACT

The first two parts of this series sought to discover the purpose of calendars in general and define a metric for evaluating how well various proposals meet that purpose. Simply put, the purpose of a calendar is to provide a uniform date structure that is strongly associated with the cyclic environmental factors that are considered important to the society that uses the calendar. This produced several metrics that culminated in a simple latitude-independent metric termed here 'seasonal dissonance'. This process clearly indicated that a mean tropical yare (Martian year) using the mean anomaly of an arbitrary tropical event was the best form of a tropical Martian calendar.

In the process of writing the first two papers, it became apparent that environmental factors are only one half of the cyclic factors that must drive the calendar design. The internal cycles of human beings are even more important. The length and consistency of these cycles are critical to human health. When we leave Earth, the cyclic environmental factors of our home planet will be lost. These factors calibrate our internal clocks and are necessary for our wellbeing. Any calendar used by human beings must take this into account. The lost signals of moonlight and tidal effects must be replaced by calendar structures and other social constructs. In addition, there are strong traditional patterns of business and government that, on Earth, conflict with each other and the natural cycles of humanity. These conflicts can and must be corrected to make the colonization of Mars successful.

INTRODUCTION

Part one of this series examined the accepted definitions and historical uses of the calendar on Earth to derive the following refined definition.

"Explicitly, a calendar is a collection of ordered, preferably uniform time units that conform to the cyclic environmental factors that are important to the society that uses it. The best calendar for a society is the one that conforms to relevant cyclic environmental factors over its useful lifespan. In a mathematical sense, since time is linear, a calendar can be understood as a linear approximation of cyclic factors over some time duration."

The true anomaly, in conjunction with the obliquity, determines the environmental factors. The mean anomaly is a linear approximation of the true anomaly over one yare and longer. Therefore, the mean anomaly must be the linear approximation of the date. The difference between this approximation of date and actual date is referred to here as the 'date dissonance'.

In the second paper this logic was followed using the values of several important environmental factors. The difference in those values at the mean and true anomalies is referred to here as the 'factor dissonance. The four separate dissonances were combined into a latitude independent metric referred to here as 'seasonal dissonance'. This metric most closely measures the appropriateness of a calendar, based on the above definitions.

There remain two aspects of the Mars calendar that were not closely examined: the asymmetry in the migration of seasonal markers over an uber-yare, and the nature and effects of intercalation. In studying the second of these, it became clear that the rhythms of Earth will have as much influence on the Mars calendar as those of the red planet. The length of day, phases of the moon, the cycle of the tides, and the change of seasons have all been embossed on our DNA, and we must take them with us wherever we go.

ANALYSIS

Asymmetry in the Migration of Seasonal Markers over an Uber-Yare

The selection of a mean tropical calendar results in all the seasonal markers oscillating about their original start dates. The chief advantage of the mean calendar is that the markers, as a group, oscillate less with a mean tropical than a tropical calendar. However, it is apparent (See Table 1.) that none of the tropical events moves symmetrically about their ideal. This small asymmetry presents over the uber-yare in much the same way as the asymmetry of seasons does over a single yare. This appears an increase in seasonal dissonance that must be addressed, but this is not so.

The asymmetry is due not to the eccentricity of the Mars orbit but the change in that eccentricity over an uber-yare. The use of the mean anomaly to define a yare minimizes the seasonal dissonance for each yare, and thus for the summation of any number of yares. The shape of the date dissonance curve flattens or heightens as the eccentricity changes. If a seasonal marker is near its maximum or minimum date dissonance when the eccentricity is high, the point may wander farther from its ideal point. (See Figure 2.)

One could minimize the largest date dissonances by adding an offset to each yare to center the median. The dark gray zig-zag line in Figure 3 addresses this. The other lines represent the possible offsets for each pair of seasonal markers based on absolute value of the date dissonance. The average can be mathematically shown to be zero if the tiny mean change in eccentricity during one yare is ignored. Adjusting the widest pair would result in less than one sol at the cost of further disturbing the symmetry of other pairs. In addition, this offset would be in addition to any intercalation offsets. For these reasons, it seems best to not make any changes in this area.

Calendar Structure

The future stakeholders in these decisions include the following. 1) Colonists living on Mars. 2) Companies operating and employees living on or about Mars. 3) Government organizations organized for the administration of parts or the entire of Mars. It is for these stakeholders that the calendar is created, so all decisions should be made solely for their benefit.

There are two proposed calendars being analyzed in this paper. One is the Zubrin Calendar, proposed by Dr. Robert Zubrin[i], the founder of the Mars Society and author of "The Case for Mars". The Zubrin Calendar is described in Part One of this series. Dr. Zubrin proposed two different strategies for intercalation. One maintained the desirable property of each yare starting on the same sol of the week. Dr. Zubrin's calendar defines months by true anomaly. The precession of the northward equinox will cause the length of the months to change over decades. This was my major criticism of this calendar.

The Darian Calendar was proposed by Thomas Gangale[ii]. There is much to like about this calendar. However, one criticism of this calendar is the use of the true anomaly to define the yare. This will cause seasonal markers to wonder up to twice as far over the calendar over millennia as using the mean anomaly. If one must use a true anomaly, the yare would be less seasonally dissonant if using something closer to one of the apsides. Either solstice would due, but the winter solstice would make this calendar a bit more like the Common Era Calendar. I also had some trivial issue with his intercalation pattern over millennia.

I have some concern with both calendars related to adding or subtracting sols from a week. This is discussed below. (See "The Sols in a Week and Circaseptan Rhythms" below.)

The Internal Structure of the Calendar and Human Factors

When the first of these three papers was being written, there was no thought of discussing the internal structure of the calendar. However, the concept of intercalation is so involved with calendar structure that one cannot address the one subject without addressing the other.

The Mars Sol and Circadian Rhythms

Circadian rhythms are those natural biological rhythms that cycle every solar day. Together with other human rhythms, they control sleep schedule, appetite, body temperature, hormone levels, alertness, daily performance, blood pressure, and reaction time.[iii] There is a startling large list of "significant biological processes associated with circadian time".[iv]

Circadian rhythms in humans are controlled by an internal (endogenous) clock but calibrated by the external environment. External factors that help calibrate biological rhythms are called 'zeitgebers'. The zeitgeber for the circadian rhythms is simply the variation in light. A rhythm primarily defined by some zeitgeber is called exogenous.

The Mars sol is 24 hours, 39 minutes, 35.244 seconds in duration. Research indicates that the sol is within the human entrainment range. This means that humans can successfully modify their circadian rhythms to the dark/light cycle on Mars.[v] While his concern is beyond the scope of this series, it was important to introduce human chronobiology before addressing the week. (See Table 2.)

The Sols in a Week and Circaseptan Rhythms

No other element of the calendar seems more culturally contrived than the week. It appears to be simply a convenient, if not perfect, division of the lunar month. Except for small enclaves of people who live much closer to nature, we no longer know or care about the phases of the moon. For examples, the ancient Romans used an eight-day week until Christianized. This would tend to give us license to use what week we wish.

However, the driving factors for a seven-sol week are biological. Seven-day (circaseptan) rhythms developed long before the first human to walk on Earth. Even plants demonstrate rhythms related to our seven-day week. For example, bean sprouts present a rhythm correlated with the phases of the moon. One quarter of this is 7 days, 9 hours, 11 minutes, and 0.744 seconds. This same research indicates that this rhythm is endogenous to the plants.[vi]

The importance of circaseptan rhythms to human health cannot be overstated. These rhythms are clearly endogenous. Some are synchronized by cyclic external variables. Others begin only after certain events, such as wounds.

An article from Sleep Medicine Clinics discusses one example circaseptan rhythm that is affected by external factors. "Numerous studies reported 7-day, and annual patterns in stroke onset. It is important to emphasize that many exogenous stressors impact the occurrence of cerebrovascular events, likely through a complex interaction with endogenous circadian rhythms. These factors may include emotional stress, napping, physical activity, medication schedules etc."[vii]

In an article written for the military in 1999, the author discussed circaseptan rhythms triggered by events. These were several of the conclusions.

"The neuroendocrine and immune system form a complex web of interactions and controls at all levels of integration. Most of the variables encountered are not stationary but show rhythms in multiple frequencies (circadian, circaseptan, circannual, and others) …

"Rhythmic infradian (most frequently circaseptan) response patterns are found during tissue regeneration, the regeneration of organs of the immune system after immunosuppression, and in the development of humoral- and cell-mediated immunity after introduction of an antigen. Similar reaction patterns can be triggered by metabolic loads. It is not known if exposure to prolonged stress as experienced in the military climate leads to the manifestation of rhythmic reaction patterns.

"Allograft rejection is characterized by rhythmicity of its clinical manifestations, with circadian and circaseptan periods observed. The relative predictability of these rhythmically occurring events may allow preventive treatment at the time when needed and no treatment or decreased dosage at times when rejection reactions are unlikely, thus decreasing undesirable side effects and cost. The feasibility of such an approach has been shown in animal experiments." [viii] An allograft is tissue graft in which the donor and recipient are same species but not otherwise genetically the same."

Perhaps more to the point are the results of the Mars 500 project. In this study European Space Agency, in conjunction with the Russian Institute of Biomedical Problems simulated a prolonged stay on Mars. This simulation lasted from February 10 of 2010 to November of 2011. This experiment included full isolation, an appropriate delay in communications, and correct Mars surface lighting. A seven-sol week was imposed upon the six subjects. Circaseptan rhythms were detected in sodium balance. One paper concluded "At constant salt intake, daily Na+ excretion exhibited aldosterone-dependent, weekly (circaseptan) rhythms, resulting in periodic Na+ storage."[ix]

The eight-day week the Romans used was 14.82 hours longer than the moon's synodic week. They eventually adopted the seven-day week, which is 9.18 hours shorter. This may be some evidence that humans can entrain to either one but prefer the closer of the two. The seven-sol week is only 4.57 Earth hours short of the moon's synodic week. An eight-sol week would be 20.09 hours longer that the moon's synodic week.

Despite some evidence that humans can sense the gravitational pull of the moon and sun, it is believed that the zeitgeber for most circaseptan rhythms are provided by the social week. This is an example of a natural rhythm causing a temporal-based social construct that replaced the natural zeitgeber. This provides hope that other such constructs can replace the zeitgebers colonists must leave behind on Earth.

There should be seven sols in a week.

Inviolate Weeks and the Experience of Daylight Savings Time

There has been little research into the consequences of disruption to circaseptan rhythms. We can only extrapolate from the great amount of research done on similar upset to circadian rhythms. Ill effects include increased chances of stroke and heart disease. There are also correlations with Parkinson's, Huntington's, and Alzheimer's diseases. A simple disruption to circadian rhythms such as the biannual daylight savings time (DST) clock changes results in decreased productivity, and an increase in accidents, depression, and suicides. The effects are so pronounced that many nations have switched, or are considering switching, to either year-round DST or year-round standard time.

We can apply our experience with DST to Mars in two separate ways. First, we can extrapolate this experience into other human chronobiology as it applies to the structure of calendars. This is covered below. Second, we can apply our knowledge concerning disruption of circadian rhythms directly to Mars. Mars not only undergoes similar changes in daylight duration over the seasons but nearly two hours of additional daylight shift due to its greater eccentricity. The problem is much smaller on Earth, and the cause is referred to as the 'Equation of Time'. This must be addressed in another paper.

The daylight savings time changes just discussed disturb circadian rhythms by only 2.4% of the cycle. Adding or removing sols from a week will disturb the circaseptan rhythm by 14.3%, or nearly 3.5 times more. Considering the circaseptan relationship with health, this may have effects of a population already under stress in a hostile and strange environment much greater than the disruptions to circadian rhythms discussed above.

Sols should not be added or removed from a week.

The Development of the Martian Economy

The colonization of Mars will go through several business-related phases. During the first phase, temporary inhabitants will be supported on the planet by those business or governmental organization that sent them. The colonists will experience no cyclic expenses on Mars, but their families or representatives will be paid on Earth relative to the appropriate Earth calendar. Earth based organizations will pay any associated taxes relative to the appropriate Earth calendar.

If it is possible for humans to live for extended periods and reproduce on Mars, there will be permanent colonists. If these conditions are not met, there may still be a succession of long term, but still temporary, inhabitants that may collectively be called colonists. Either situation will eventually produce a situation where company or independent stores will evolve to service these colonists. The colonists themselves will directly receive some or all their pay on Mars. This produces an economy that will require some elements of a Mars.

The Mars economy will ultimately produce weekly and monthly bills that occur relative to the Mars calendar. At this point all pay will occur by the same calendar. One or more governments of some level will have evolved on the planet. Corporations may be required or prefer to pay Mars taxes according to the Mars calendar. New companies will be incorporated under Martian law,

The details of this development are highly speculative and beyond the scope of this paper. The remainder of this paper assumes nothing more than the above evolution will take place in some way at some time.

Whole Weeks and Fortnights in a Month

It may be centuries before the economy of Mars has developed enough for it to make sense to pay employees or tax businesses based on Mars according to Martian periods. It is not too early to consider these eventualities and what issues the wrong selection in a calendar might cause. It is important to keep in mind that the following issue may be considered simply a surrogate for all issue that arise due to the conflict of the very strong circaseptan rhythm that people live by and the longer constructs the business and government follow.

It is widely believed that employees prefer to be paid by the week or fortnight, because this coincides with the weekly cycle of life. Businesses prefer to pay semi-monthly or monthly because it entails less effort in calculating payroll and coincides with tax and reporting periods.

There is some recent consideration of paying employees daily, but there are a number or issues that may keep this from happening. A related 'early pay' method causes employees to spend more money, which may not be the best thing for lower-income or compulsive spenders.

Businesses may implement daily pay with fees involved. Smaller businesses may find the overhead too expensive and having so much money tied up may limit their ability to react to sudden problems or opportunities. This paper assumes that traditional payments will continue or other differences interactions that involve the week of the employee and the month of the business may evolve.

The common era calendar involves a continuous stream of inviolate weeks and a stream of varying-length months. There is no coordination between the two. It is as if there are two separate calendars being used. This creates a situation where the number of workdays varies from month to month. This makes it more costly to determine the paychecks of hourly workers who are paid weekly, biweekly, or monthly. Salaried employees that are paid weekly or biweekly have two paydays in some months and three in others. While some workers think of this third payday as a bonus, it can also be a problem for those who live closer to each paycheck. Companies must report on quarters that may have anywhere between 12 and 14 paydays, with the accompanying tax and profit anomalies.

Most of the above problems can be eliminated if months were composed of whole weeks. To accommodate pay periods of two weeks, months consisting of whole fortnights would be preferred. That does not mean that months must start on the same sol of the week. One month of the yare must be a distinct size to allow intercalation. If the last month is used for intercalation, all months within the same yare must begin on the same sol of the week. Allowing the start sol of the month to vary allows for an intercalation strategy based on the sol. Only an intercalation pattern based on the week results in every start sol of the yare being the same sol of the week.

There should be whole weeks, and preferably whole fortnights in a month.

The Number of Weeks in a Month

The month of the Common Era Calendar averages 30.44 days and has proved to be a useful, if flawed, length of time for business and government. That equates to 29.62 sols. This implies that, by tradition and the above conclusion, a month on Mars should be four weeks or 28 sols. The consideration of human circalunar rhythms is a much less clear process but provides an obvious and simple solution for the length of a month.

There is not just one lunar month, there are four. The first is the sidereal month. This is the time for the moon to return to the same position against the background stars as seen from Earth. There are no natural rhythms that follow this month. The second is the synodic month. This is the time between full moons. That can also be defined as the time between the moon's opposition to the sun. A vast number of species.synchronize to this cycle, particularly regarding reproduction. The third month is the tidal month, or the time between spring tides, This has the same cause and mean period as the synodic month but is complicated by time delays and the varying times any spot on Earth may be under the moon. No purely terrestrial species synchronize to this month. The fourth is the anomalistic month. The moon travels in an ellipse about Earth, being closest to the planet at perigee and farthest at apogee. The gravitational pull of the moon at perigee is 26% than it is at apogee. This this may be the primary effect of this month, chronobiological rhythms that synchronize to this cycle are sometimes referred to as gravitational rhythms. There is some sparse evidence of human chronobiological rhythms that follow this cycle, particularly regarding neurology. As far as calendars are concerned, only the synodic and gravitational months are important.

The calendar week, with workdays and weekends, is a very strong social construct that replaced the original zeitgeber. The same is not true for the calendar month. There is no strong social pattern associated with the calendar month, and it never supplanted the fading influence of the phases of the moon. Circalunar rhythms that followed the synodic month run free in societies that are not close to nature. It is unlikely that the calendar month on Mars would create such a relationship.

The Mars 500 project mentioned above did not implement any monthly variation in environment of any kind, only a seven-sol week. A monthly periodicity was detected in the all-male crew. "Changes in total-body Na+ (±200–400 mmol) exhibited longer infradian rhythm periods (about monthly and longer period lengths) without parallel changes in body weight and extracellular water and were directly related to urinary aldosterone excretion and inversely to urinary cortisol, suggesting rhythmic hormonal control." [ix]

If gravitational rhythms are both real and desirable, they will obviously lose their zeitgeber on Mars. There is little that can replace it. We cannot vary the gravity on Mars. We can only offer some strong social variation of the right length or vary the nocturnal light in public areas. The altered zeitgeber of circaseptan rhythms is a hint that rhythms can switch zeitgebers. If so, either of the above options might cause entrainment of synodic rhythms. Some of the synodic synchronous elements that were advantageous to our hunter-gatherer ancestors may have been synchronous female rhythms, births, and sleep variations. One must consider the social, economic, and health planning effects of each of these possibilities and more. It may be possible to provide nocturnal public lighting following a shorter cycle to which the gravitational rhythms may entrain but the synodic rhythms may not.

Whatever technique is applied to address these issues, it is not a calendar issue. Calendar periods that have strong social patterns built about them will affect the chronobiological rhythms of the colonists, but months and circalunar rhythms need not, and possibly must not, have any association. This allows selecting the month closest to the month used on Earth.

The month should have four full weeks.

Disrupted Circalunar Rhythms

As discussed above, the ability to disassociate any necessary circalunar zeitgeber from the calendar means any convenient length of month is acceptable. This also means that no choice of intercalation strategy is prohibited by length of the month of intercalation. The chosen strategy must keep whole weeks together. Both strategies under consideration meet these criteria.

The intercalation strategy is not constrained by the length of the month of intercalation.

The Number of Months in a Yare

Based on the length on the month, there will be 24 months. This number is divisible by four (to mirror the seasons) and eight.to provide octal reporting periods of similar length to reporting quarters on Earth.

A yare should have 24 months.

Leap Sols or Leap Weeks

Even assuming inviolate weeks, it is possible to have a single-sol intercalation pattern. This would mean that yares begin on different sols, and a single page perpetual calendar would not be possible. This would not violate having months containing an even number of full inviolate weeks, since the months (except for the 24 or 25-sol month of intercalation) would have 28 sols. A single sol of intercalation does not affect date dissonance of seasonal dissonance very much. The maximum added difference in the date difference of any sol will reach just over one- and one-half sols. The RMSE of the date dissonance over a yare will increase by just over 0,6%.

A week-based intercalation pattern is also possible. This would mean that all yares begin on the same sol of the week, and a single-page perpetual calendar would be possible. (See Figure 1.) Every month of every yare would start on the same sol of the week. All months (except for the 21 or28 sol month of intercalation) would have 28 sols. The maximum added difference in the date difference of any sol will reach just over 5.11 sols. The RMSE of the date dissonance over a yare will increase by just over 6.5%. This is not significant in comparison with the same value for the non-mean tropical yares. The week-based intercalation does not generate as much date dissonance as one might expect. While the shift in start date increases the dissonance in in a little over half of the yare, it reduces the dissonance in the remainder. (See Figure 4.) This results in an equally muted increase in seasonal dissonance. (See Figure 5 and Figure 6.)

There is no compelling reason to choose between a sol-based or week-based intercalation.

The Epoch

To complete the analysis of the Mars Calendar problem, I repeat a paragraph from the first paper in this series.

“A modified calendar could indicate a preference to a particular epoch without formally requiring it. If the northward equinox is the calibrating seasonal marker, one would expect the epoch to begin when the equation of date for that point is zero. That is also the time when the northward equinox occurs at an apsis. The most recent apsis-northward equinox conjunction was about 5,994 yares (11,274 years) ago. That would be 9,251 BCE. This was near the end of the Younger Dryas on Earth. This geological event may have triggered the start of agriculture and would be an excellent zero yare to encompass the history of an expanding human civilization. This is, coincidentally, close to the beginning of the proposed Holocene calendar[x] which begins its epoch in 10,000 BCE. Also, in 2013 the International Union of Geological Sciences (IUGS) adopted the year 9,700 BCE as the beginning of the Holocene (post-glacial) epoch[xi]. This may provide some basis for a future interplanetary epoch."

Reporting Periods

This structure of financial and other reporting periods is technically not a matter for calendar design. Since this paper considers other business issues, it would be remiss not to address this here. Large corporations and government agencies have an interest in reporting periods.

When the Mars economy is in early development, companies with operations on Mars will report according to the laws and regulations of their home nation. This will continue for larger corporations that operate primarily on Earth. One might expect that eventually Mars would produce its own companies, corporations, and industries. This would require separate reporting periods that reflect seasonal revenues and expenses. This necessarily requires conforming to the Mars calendar. The octant is about 16/17 of an Earth quarter and presents a duration with some familiarity and usefulness.

There is a synchronicity between the orbits of Earth and Mars. Seventeen Martian yares end within several sols of 32 Earth years. Therefore, there are 128 reporting quarters on Earth, while there are 126 reporting octants on Mars. That can reduce to a four-year period where there are 16 reporting quarters on Earth and 17 reporting octants on Mars. Four years, or two and one eighth yares appears to be a natural period for coordinating and comparing economic activities.

For as much as it concerns the calendar, eight reporting octants based on fully contained months appears preferrable.

The Length of the Yare

The one unit of time that presents the most challenging obstacle to Mars colonization is the passing of the four seasons itself. While this is beyond the scope of this paper, a list of calendar-related human chronobiological rhythms would be incomplete without mentioning the yare.

Circannual rhythms are, once again, endogenous. Evidence of this is found in numerous species from microbes to humans. Once again, this rhythm can be synchronized by outside influences, primarily the seasonal changes in light and temperature. While internal lighting and medication will obviously have an impact, it is not clear that humans can be entrained to yare nearly twice as long as a year. No calendar or time keeping change can address this issue. Perhaps a safe way might be found to inhibit the circannual internal clock and leave the rhythms exogenous. There is some discussion that the circannual rhythm may be controlled by a shorter endogenous clock that triggers a sampling of the light and/or temperature conditions to determine the time of the seasons. If so, humans may be able to entrain to the Martian yare. In either case, this is not a calendar issue.

The Length of the Winter

One more time period is worth mentioning, if only to emphasize how difficult life may be on Mars and why every effort to ease adaptation must be made. The calendar cannot address this.

During its brightest sols nearest the sun, Mars receives only half the average light that Earth does. During its darkest sols farthest from the sun, Mars receives only a little more than one third that of Earth. Even living at the latitude on Mars with the brightest winter sols, 30 degrees north latitude, there will be a winter twice as long and twice as dark. The collection of maladies known collectively as 'seasonally affective disorder' (SAD) may be a much larger issue than on Earth. SAD usually affects people beginning in the fall and lasting through the winter months. According to the Mayo Clinic[xii], the symptoms are as follows.

"

- Feeling listless, sad or down most of the day, nearly every day
- Losing interest in activities you once enjoyed
- Having low energy and feeling sluggish
- Having problems with sleeping too much
- Experiencing carbohydrate cravings, overeating and weight gain
- Having difficulty concentrating
- Feeling hopeless, worthless or guilty
- Having thoughts of not wanting to live
- Oversleeping
- Appetite changes, especially a craving for foods high in carbohydrates
- Weight gain
- Tiredness or low energy "

Because of the obvious difficulties in performing experiments on human entrainment to the Martian conditions, little (if any) research has been done. Ther one indication that entrainment to the long darkness is possible is the human populations that exist near or beyond the artic circle. A realistic experiment would require both the pattern of daylight and the brightness of the light to match those of Mars over one or more yare. This may require continually changing latitudes to match the length of Martian daylight, and wearing special glasses whenever being or simply looking outside to match the dim light at Mars. More research should be done in this area, if possible.

Intercalation

The Encyclopedia Britannica defines 'intercalation' as "insertion of days or months into a calendar to bring it into line with the solar year (year of the seasons). One example is the periodic inclusion of leap-year day (February 29) in the Gregorian calendar now in general use..."[xiii]

Wikipedia adds the possibility of a week to this. "**Intercalation** or **embolism** in timekeeping is the insertion of a leap day, week, or month into some calendar years to make the calendar follow the seasons or moon phases..."[xiv]

Since the moons of Mars are unlikely to play the significant role that Earth's moon has played in human history, it is reasonable to limit intercalation to addressing the seasons. To be specific, intercalation is the insertion of days, weeks, or months to reduce seasonal dissonance over an extended duration**.**

With a perfect definition of the Martian orbit over the next uber-yare, it would be possible to describe a single intercalation domain. Pending a more precise determination of the changes in eccentricity, precession of the equinox, precession of the perihelion, and changes in semi-major axis; the following intercalation strategies are presented. One is a sol-based strategy that varies the yare by one sol, and the other a week-based strategy that varies the yare by one full week.

The common features are as follows.

- The first yare of the epoch will be yare zero.
- In principle, the yare will begin when Mars is at the mean anomaly of some seasonal marker, presumedly the northward equinox**.** One advantage of using a mean tropical yare is that the choice of the Ls value to start the yare is completely arbitrary.

The properties of the sol-based strategy are as follows.

- Every odd yare and yare divisible by 10, except yares divisible by 267 will be 669 sols.
- All other yares will be 668 sols.
- The beginning of the yare will be affected by the intercalation as much as 1.57 sols in either direction. The resulting pattern of date dissonance cannot easily be described. (See Figure 7 and Figure 8.)
- The reporting period for the last octant will be 1.2% shorter than the others every yare.

The properties of the week-based strategy are as follows.

- Every odd yare will be 96 weeks long.
- Every even yare, except those divisible by 76 will be 95 weeks long.
- Every 76th yare will be 96 weeks long.
- The beginning of the yare will be affected by the intercalation as much as 5.11 sols in either direction. Yare one will end 5.11 sols after the mean anomaly of the vernal equinox. Yere 75 yare will start at 5.11 sols before the mean anomaly, but three long yares in a row will cause yare 77 to end 5.11 sols after the mean anomaly, the same as yare one. (See Figure 9.)
- The reporting period for the eighth octant will be 4.16% longer or shorter than the others each yare.

Many other intercalation patterns are possible. There is no recognized algorithm known to this author that determines an intercalation pattern. There is no recognized criteria for what makes a good intercalation pattern other than long-term accuracy.

There is no compelling reason to choose between the sol-based or week-based intercalation.

Finally, we must consider in which month to execute the intercalation. This decision is simply a matter of convenience. If the sol-based intercalation strategy is selected and uses the last month for intercalation, the same date of every month in any one yare will fall on the same sol of the week. If the week-based intercalation strategy alone is selected, the same date in every month in every yare will fall on the same sol of the week. Using the last month for intercalation means that fortnights begin on the sane date of the month in any one yare.

The month of the intercalation should be the last month of the yare.

CONCLUSIONS

The first paper in this series demonstrated that the wandering of the seasons over the calendar is minimized by adopting the mean tropical yare and using the mean anomaly of a seasonal marker to begin each yare. The second paper demonstrated that this approach would also reduce date instability in three of four key cyclic environmental factors. The fourth factor followed the apsidal cyclic and cannot be reconciled to any tropical calendar. Together these papers showed that every date on the calendar would experience similar movement within the seasons and could be used as important markers by some future society.

This third paper demonstrates that the structural components are nor arbitrary but are determined by endogenous rhythms ignored at health risk to the future colonists. Colonizing Mars will be such a difficult and risky challenge that this consideration may make a significant difference to success. The imperfect options for intercalation were also examined in the light of these constraints.

- There should be seven sols in a week. (Reasons: tradition and biology)
- Sols should not be added or removed from a week. (Reason: biology)
- There should be whole weeks, and preferably whole fortnights in a month. (Reasons: business, government, and convenience)
- The month should have four full weeks. (Reason: tradition)
- The intercalation strategy is not constrained by the length of the intercalation month. (Reason: biology)
- A yare should have 24 months. (Reason: remaining option)
- For as much as it concerns the calendar, eight reporting octants based on fully contained months appears preferrable. (Reason: tradition)
- There is no compelling reason to choose between the sol-based or week-based intercalation.
- The month of the intercalation should be the last month of the yare. (Reason: convenience)

Designing by these rules produces a calendar and environment that is more easily adapted to by Mars colonists. (See Table 2.) It is worth noting that the Mars calendar has units that are closer to the circaseptan and apsidal circalunar cycles than the calendar units of the Common Era Calendar.

The calendar also corrects the tension between weeks and months that translates to some issues for employees and employers. The first two papers in this series assured that the relationship between calendar date and environmental factors will be maintained as well as possible over many millennia.

There is little to separate the two forms of intercalation. Both satisfy all criteria except minimum seasonal dissonance and equal-sized reporting periods. The sol-based interaction has less of an effect on seasonal dissonance, but both are significantly below other options. The week-based intercalation produces identical months (except the last) in perpetuity. It also has only one unequal reporting period for two yares; almost four years on Earth. The sol-based option has twice as many but of half the size. This may be settled as further research may find another criterion not addressed in this series.

Note: A lack of existing terminology makes calendar design difficult to discuss. To address this, several new concepts and definitions were introduced in this series. Two are metrics for evaluating how well the calendar fulfills its major purpose of conforming to the seasons while being uniform and consistent, date dissonance and seasonal dissonance. Para-seasons were conceived to better define seasons on a world with short delay between peak insolation and peak temperature and to match the daylight and solar energy seasons we informally recognize on Earth. Four existing Celtic names and symbols were introduced to reference the resulting seasonal boundaries. The uber-seasons and uber-yare were defined to provide a straightforward way of describing the cyclic relationship between the apsidal effects of eccentricity and the tropical effects of obliquity.

FURTHER RESEARCH

- The length of the yare and uber-yare must be further refined based on the latest measurements. This should not affect the conclusions of this paper, but simply increase the accuracy of the mathematics.
- Future changes to eccentricity must be determined to a higher degree of accuracy.
- The impact of shorter terminal horizons on the calendar deserves examination.
- If the future population of Mars clusters near the equator, more than one half of the population will live within the area where the climate is dominated by the eccentricity of the orbit and not the obliquity. In that case, an apsidal (anomalistic) calendar is more appropriate. (See Figure 10)
- Further thought and study should be put into the epoch. There may be good educational reasons for choosing an epoch that spans all human history. A start yare at the beginning of the Holocene may provide a better perspective on the scope of human civilization and Mars' place within it.
- This author is unaware of any study having been done concerning disruptions to any chronobiological rhythm longer than circadian.

TABLES

Table 1: Evolution of Date Dissonances over Uber-Yare

Date Dissonance Skew Over Uber-Yare			
Symbols	**Seasonal Markers**	**L_S**	**Skew**
♈	Northward Equinox	0.00000	-0.056145657
	Beltain	0.78540	0.039921726
♋	Northern Solstice	1.57080	0.051701474
	Lamas	2.35619	-0.036545471
♎	Southward Equinox	3.14159	-0.008516292
	Samhain	3.92699	0.077762341
♑	Southern Solstice	4.71239	0.007922244
	Imbolic	5.49779	-0.076185558

Table 2: Chronobiology and the Mars Calendar

Suitability of Calendar for Chronobiology Rhythms					
	Circadian	**Circaseptan**	**Circalunar (Synodic)**	**Circalunar (Anomalistic)**	**Circannual**
Duration in Days	1.0000	7.3826	29.5306	27.5546	365.2422
Earth Construction	1.0000	7.0000	30.4368	30.4368	365.2422
Earth Difference	0.000%	-5.183%	3.069%	10.460%	0.000%
Mars Construction	1.0275	7.1560	28.6239	28.6239	686.9725
Mars Difference	2.749%	-3.070%	-3.070%	3.881%	88.087%
Entrainable	YES	Probable	Probable	Probable	Probably not

FIGURES

Figure 1: Perpetual Calendar Using Week-Based Intercalation

Perpetual Mars Calendar

First Octant

Alpha							Beta							Gamma						
1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7
8	9	10	11	12	13	14	8	9	10	11	12	13	14	8	9	10	11	12	13	14
15	16	17	18	19	20	21	15	16	17	18	19	20	21	15	16	17	18	19	20	21
22	23	24	25	26	27	28	22	23	24	25	26	27	28	22	23	24	25	26	27	28

Second Octant

Delta							Epsilon							Zeta						
1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7
8	9	10	11	12	13	14	8	9	10	11	12	13	14	8	9	10	11	12	13	14
15	16	17	18	19	20	21	15	16	17	18	19	20	21	15	16	17	18	19	20	21
22	23	24	25	26	27	28	22	23	24	25	26	27	28	22	23	24	25	26	27	28

Third Octant

Eta							Theta							Iota						
1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7
8	9	10	11	12	13	14	8	9	10	11	12	13	14	8	9	10	11	12	13	14
15	16	17	18	19	20	21	15	16	17	18	19	20	21	15	16	17	18	19	20	21
22	23	24	25	26	27	28	22	23	24	25	26	27	28	22	23	24	25	26	27	28

Fourth Octant

Kappa							Lambda							Mu						
1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7
8	9	10	11	12	13	14	8	9	10	11	12	13	14	8	9	10	11	12	13	14
15	16	17	18	19	20	21	15	16	17	18	19	20	21	15	16	17	18	19	20	21
22	23	24	25	26	27	28	22	23	24	25	26	27	28	22	23	24	25	26	27	28

Fifth Octant

Nu							Xi							Omicron						
1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7
8	9	10	11	12	13	14	8	9	10	11	12	13	14	8	9	10	11	12	13	14
15	16	17	18	19	20	21	15	16	17	18	19	20	21	15	16	17	18	19	20	21
22	23	24	25	26	27	28	22	23	24	25	26	27	28	22	23	24	25	26	27	28

Sixth Octant

Pi							Rho							Sigma						
1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7
8	9	10	11	12	13	14	8	9	10	11	12	13	14	8	9	10	11	12	13	14
15	16	17	18	19	20	21	15	16	17	18	19	20	21	15	16	17	18	19	20	21
22	23	24	25	26	27	28	22	23	24	25	26	27	28	22	23	24	25	26	27	28

Seventh Octant

Tau							Upsilon							Phi						
1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7
8	9	10	11	12	13	14	8	9	10	11	12	13	14	8	9	10	11	12	13	14
15	16	17	18	19	20	21	15	16	17	18	19	20	21	15	16	17	18	19	20	21
22	23	24	25	26	27	28	22	23	24	25	26	27	28	22	23	24	25	26	27	28

Eighth Octant

Chi							Psi							Omega						
1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7
8	9	10	11	12	13	14	8	9	10	11	12	13	14	8	9	10	11	12	13	14
15	16	17	18	19	20	21	15	16	17	18	19	20	21	15	16	17	18	19	20	21
22	23	24	25	26	27	28	22	23	24	25	26	27	28	22	23	24	25	26	27	28

Figure 2: Migration of Seasonal Markers across Calendar over Uber-Yare

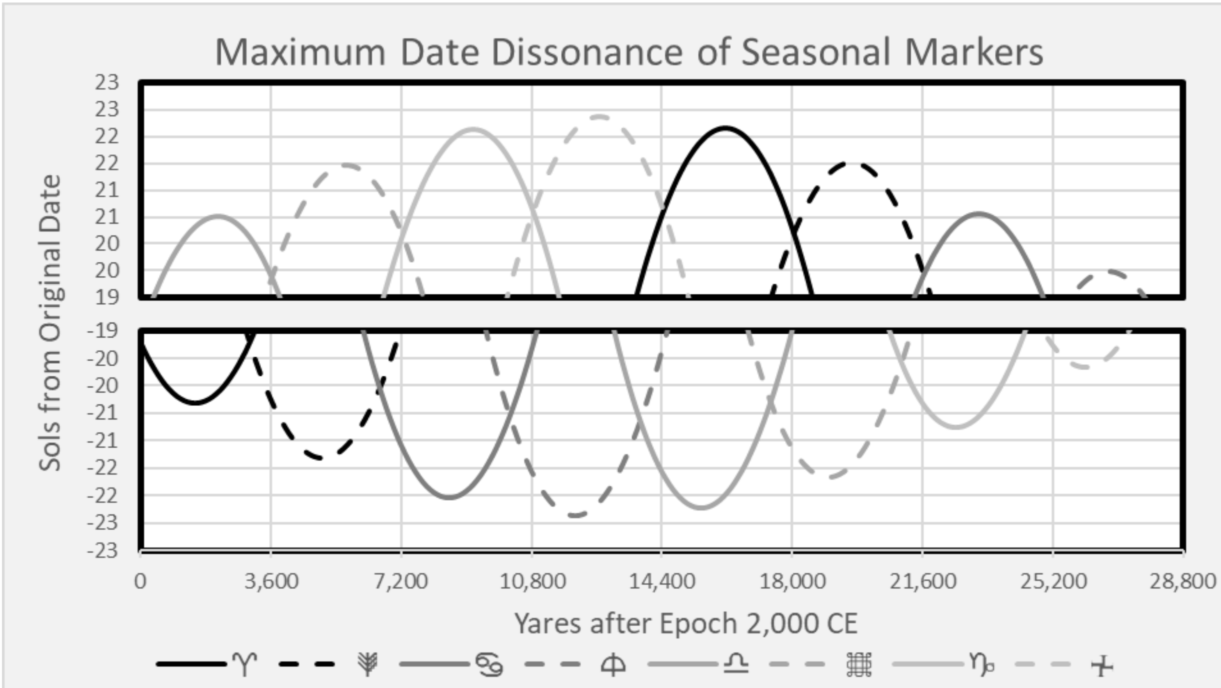


Figure 3: Possible Sol Offsets by Asymmetry Pairs

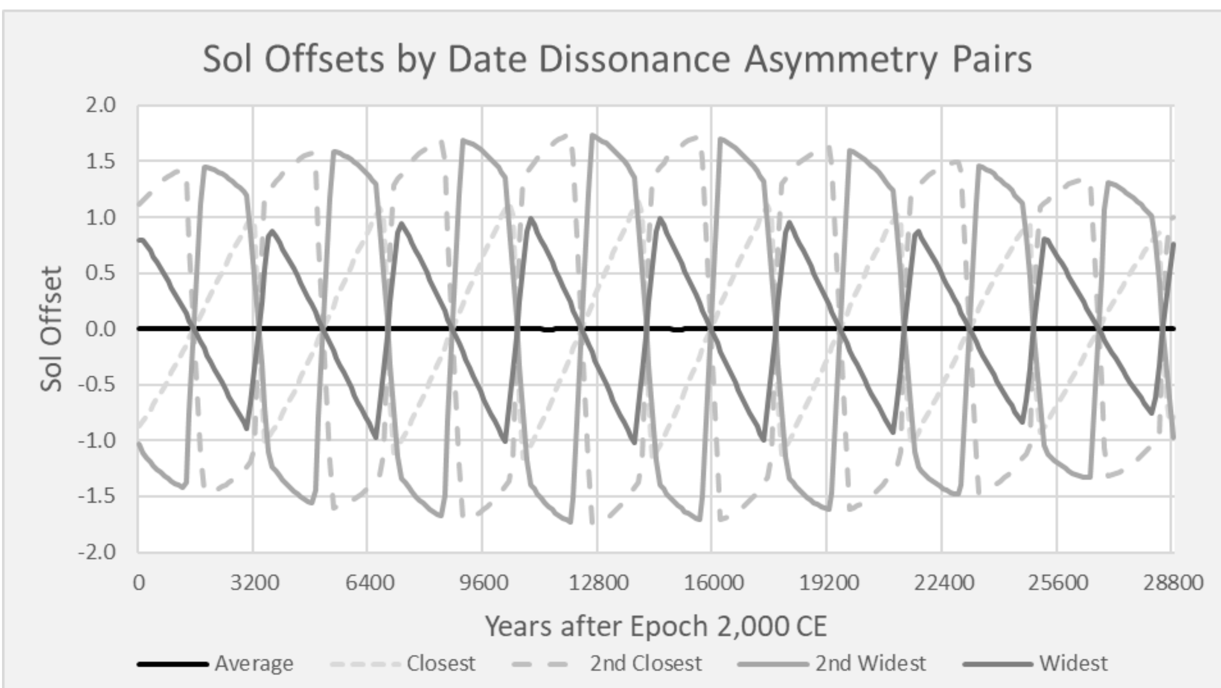


Figure 4: The Effect of 7-Sol Intercalation on Date Dissonance

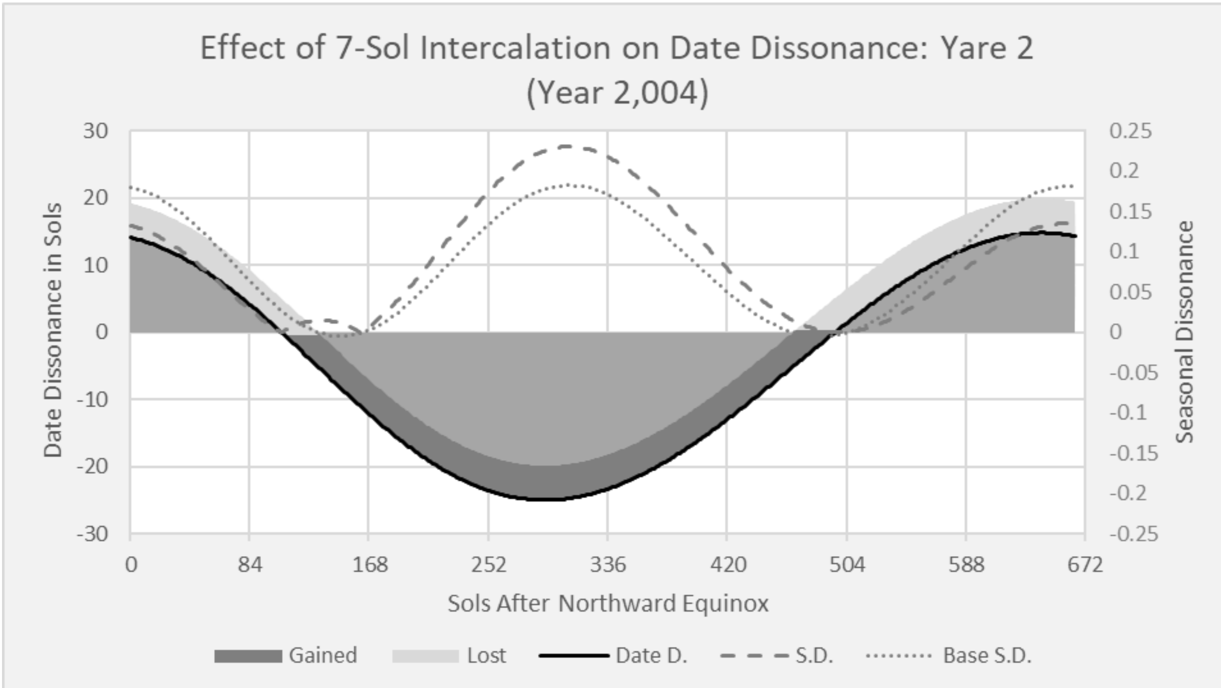


Figure 5: The Effect of 7-Sol Intercalation on Seasonal Dissonance

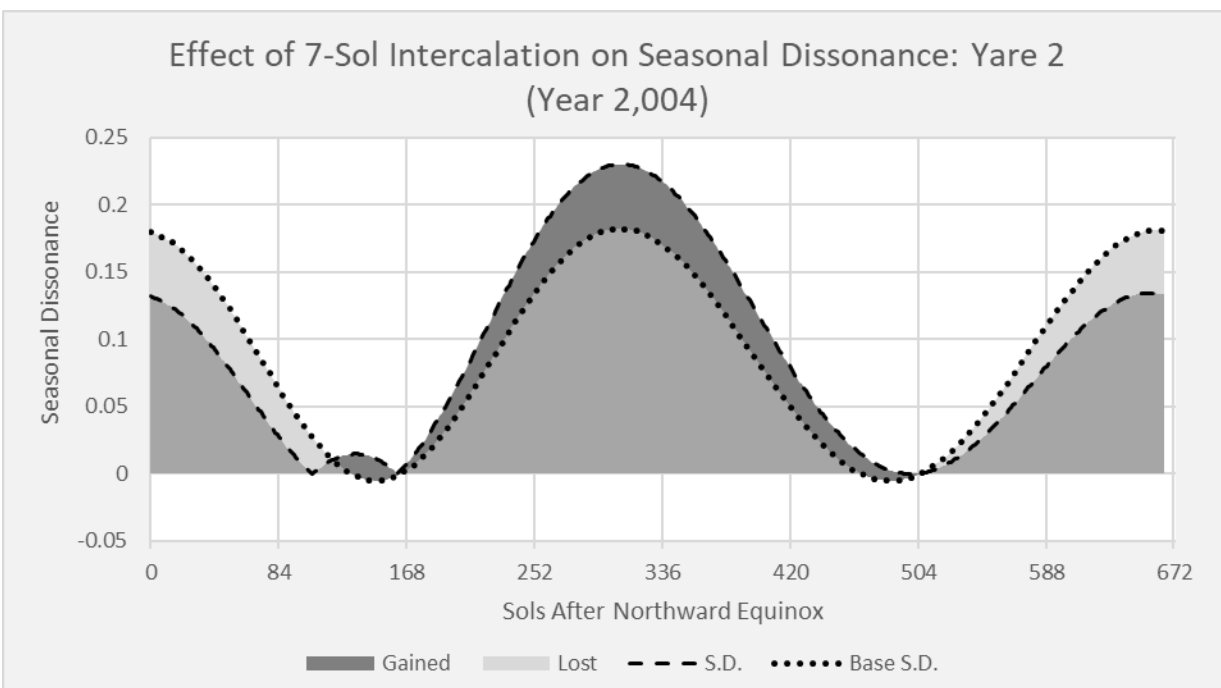


Figure 6: The Effect of 7-Sol Intercalation on the Change in Seasonal Dissonance

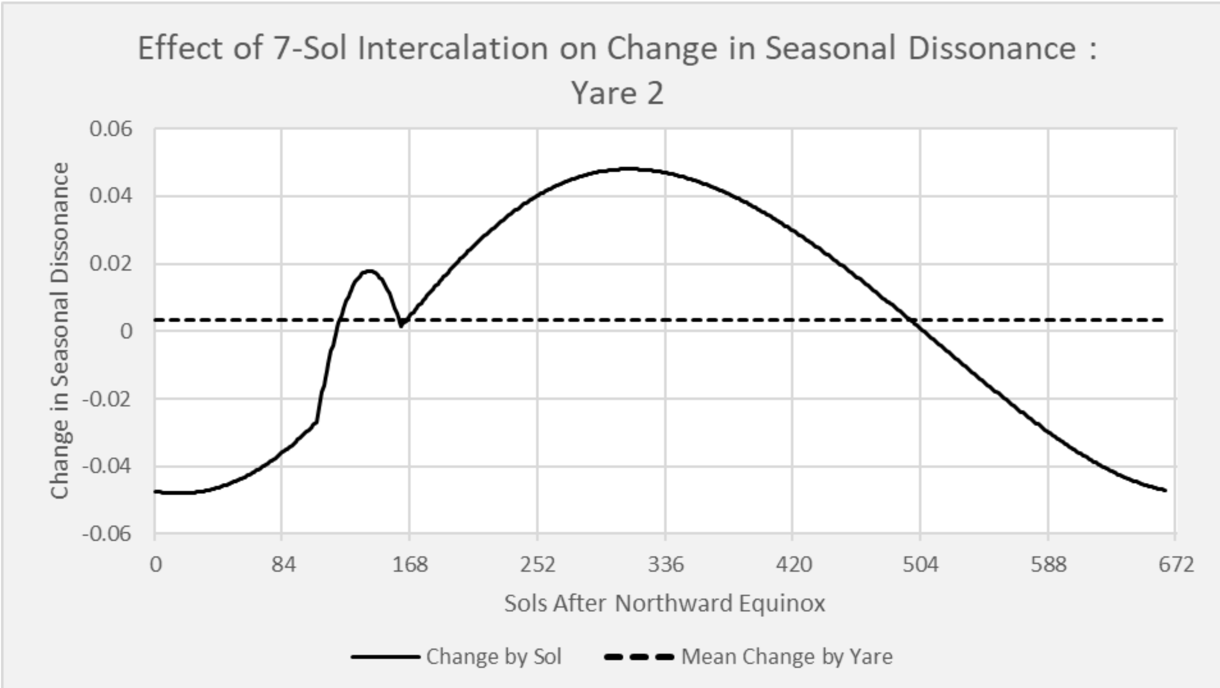


Figure 7: Migration of Start Sol Offset with 1-Sol Intercalation (Yares 1-250)

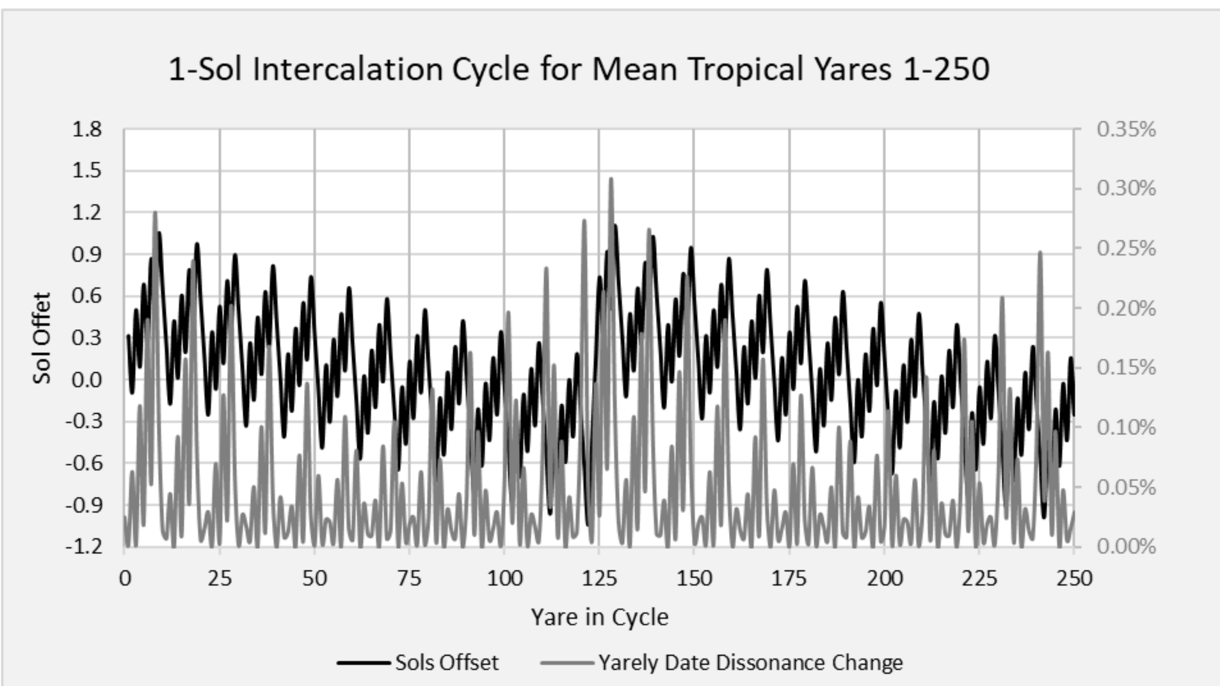


Figure 8: Migration of Start Sol Offset with 1-Sol Intercalation (Yares 4751-5000)

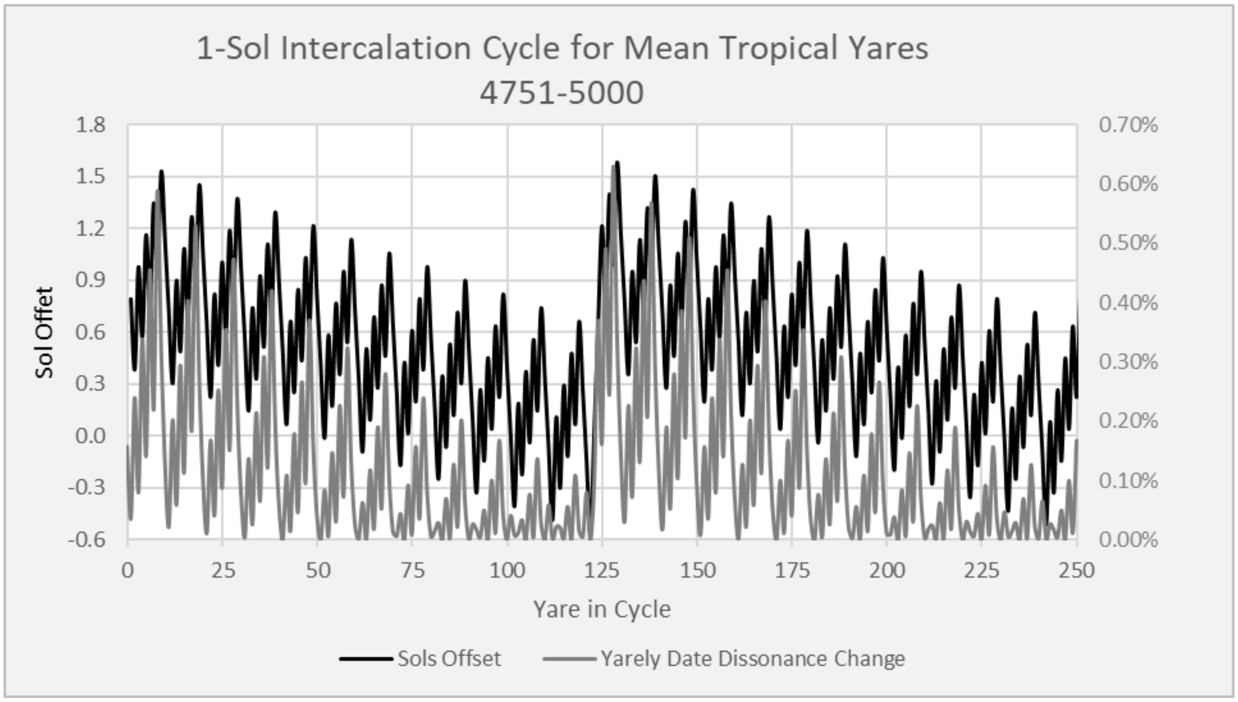


Figure 9: Migration of Start Sol Offset with 7-Sol Intercalation

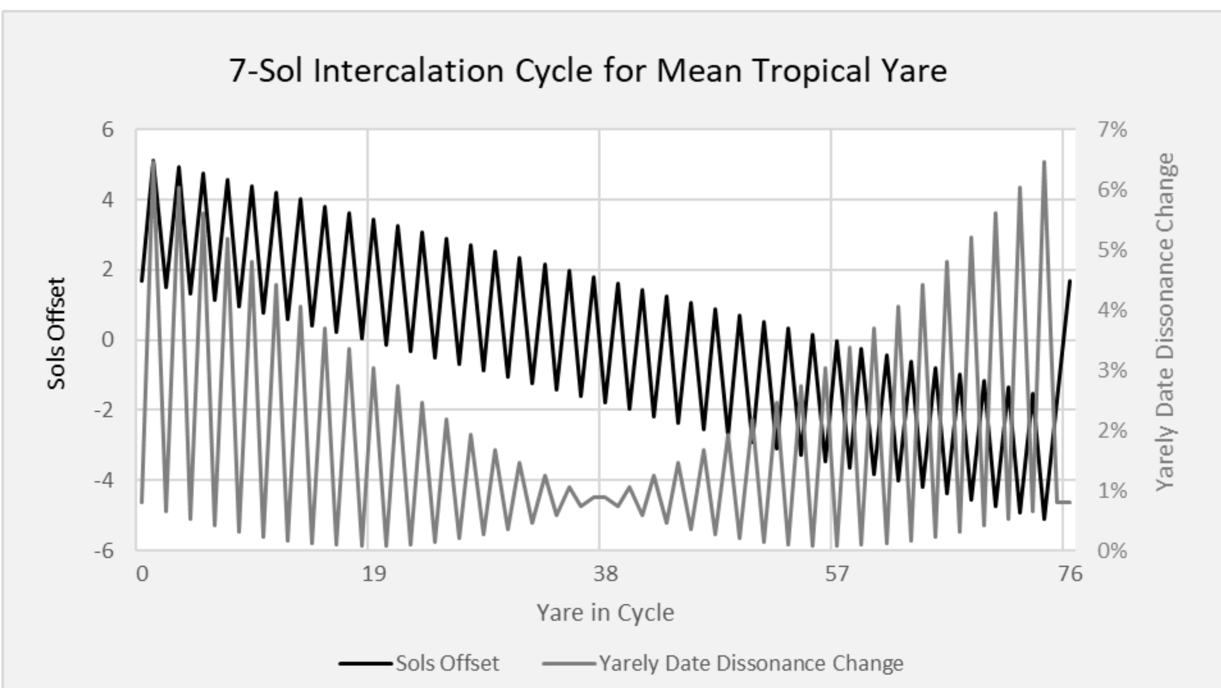
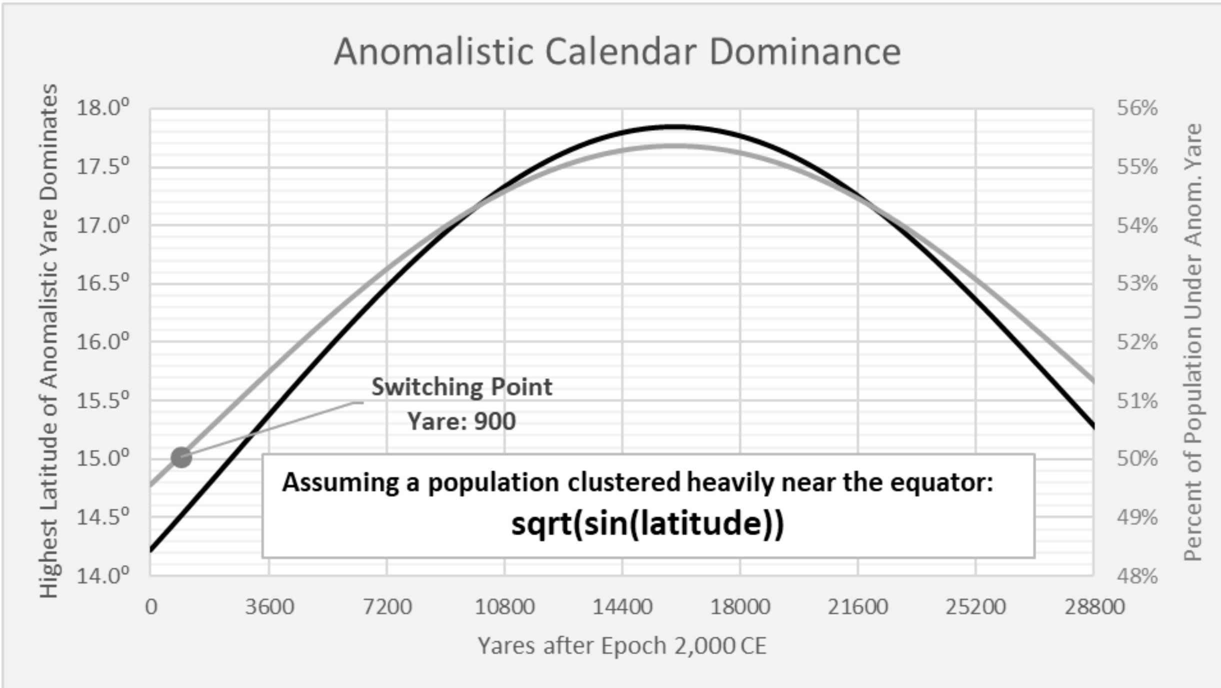


Figure 10: Rationale for an Anomalistic Calendar



NOTES

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