Perihelion precession, polar ice and global warming

Duncan Steel

Email: pppigw@duncansteel.com

Summary: The increase in mean global temperature over the past 150 years is generally ascribed to human activities, in particular the rises in the atmospheric mixing ratios of carbon dioxide and other greenhouse gases since the Industrial Revolution began. Whilst it is thought that ice ages and interglacial periods are mainly initiated by multi-millennial variations in Earth's heliocentric orbit and obliquity, shorter-term orbital variations and consequent observable climatic effects over decadal/centurial timescales have not been considered significant causes of contemporary climate change compared to anthropogenic influences. Here it is shown that the precession of perihelion occurring over a century substantially affects the intra-annual variation of solar radiation influx at different locations, especially higher latitudes, with northern and southern hemispheres being subject to contrasting insolation changes. This north/south asymmetry has grown since perihelion was aligned with the winter solstice seven to eight centuries ago, and must cause enhanced year-on-year springtime melting of Arctic (but not Antarctic) ice and therefore feedback warming because increasing amounts of land and open sea are denuded of high-albedo ice and snow across boreal summer and into autumn. The accelerating sequence of insolation change now occurring as perihelion moves further into boreal winter has not occurred previously during the Holocene and so would not have been observed before by past or present civilisations. Reasons are given for the significance of this process having been overlooked until now. This mechanism represents a supplementary – natural – contribution to climate change in the present epoch and may even be the dominant fundamental cause of global warming, although anthropogenic effects surely play a role too.

Introduction

Record melting of Arctic sea ice over the past year (Schiermeier 2012) has been widely presumed to be a consequence of anthropogenic global warming (AGW), and yet a natural mechanism exists that may be responsible, at least in part.

The widespread belief that AGW is the fundamental cause of present-day climate change is predicated on the apparent correlation between rising levels of carbon dioxide and the increase in mean global temperature over the past two centuries. Simple considerations of the effect of carbon dioxide, water vapour and methane on the infra-red opacity of the atmosphere lead to an expectation that as the proportions of those gases rise, so should the temperature. This provides a reason to think that in this case the correlation has a cause, and is not simply a coincidence.

Correlation, however, does not demonstrate causality, and the possibility remains that this is either a coincidence, or that some other factor(s) may be involved in the warming. The case for AGW being the dominant cause of climate change would be weakened should some other causative agency be identified that also has a temporal correlation with the rising temperature.

In this article I present *prima facie* evidence that the ongoing natural increase in spring insolation occurring at high northern latitudes, coupled with the positive feedback effect of the resultant snow and ice loss reducing the region's mean albedo over summer, comprises just such a causative agency. This concept frames a working hypothesis in which the melting of Arctic ice is not so much a *consequence* of global warming as its *cause*. In this picture AGW due to rising levels of greenhouse gases remains as a contributor to the overall warming, but is not necessarily the dominant influence.

The changing insolation theory (CIT) mooted herein is capable of explaining various observed phenomena which the AGW hypothesis has not yet been able to accommodate. Specifically, what has been observed and is pertinent here are the following:

1. A gradual rise in mean global temperature over the past two centuries;
2. Accelerating spring and summer melting of Arctic sea ice reaching an extent not previously witnessed;
3. No substantial loss of Antarctic sea ice, and actually a small growth in its extent (Shepherd *et al.* 2010; Parkinson and Cavalieri 2012);
4. The greatest rises in regional temperatures (and temperature variability) being at high northern latitudes (Liu *et al.* 2007; Wu *et al.* 2011).

Astronomical context

The precession of the longitude of perihelion [$\tilde{\omega}$] referenced to the equinoxes/solstices takes *circa* 21,000 years to complete a revolution around the ecliptic (Huybers 2009), and in doing so alters the lengths and characters of the seasons independent of other parameters (such as the secular oscillations in orbital eccentricity and the obliquity of the ecliptic, often termed "Milankovitch forcings", that are thought to result in ice ages and interglacial periods: Crucifix *et al.* 2006; Raymo and Huybers 2008). Over the past 5,000 years the eccentricity [e] has been monotonically decreasing, from a value of 0.0184 to the present 0.0167; Earth's obliquity or spin axis tilt [ε] has also been monotonically decreasing, from $24.^{\circ}02$ to $23.^{\circ}44$; while $\tilde{\omega}$ has been systematically increasing, from 198° to the present 283° (see Table 1 for particular values: these were computed using the formulation of Berger 1978).

If e and ε are assumed invariant (and similarly the intrinsic solar output taken to be unchanging) then the total annual influx of solar radiation to the Earth remains sensibly constant* but its latitudinal distributions at different times of year alter under perihelion precession, and this is reflected in changes in the seasons themselves. The lengths of the astronomical seasons (as determined by the intervals between the equinoxes and solstices) alter by several days over multi-millennial time scales. For example, in the northern hemisphere (NH) summer is now almost four days longer than it was 5,000 years ago, whilst over the same period NH spring first grew in length by about a quarter of a day and then shrank so as to be about a day-and-a-half briefer now than it was five millennia ago. In the southern hemisphere (SH) summer is now about 3.6 days shorter than 5,000 years back; and so on.

In the mid-13th century Common Era (CE) perihelion was aligned with the winter solstice, making autumn and winter the same duration as each other and briefer than the other equal-duration pair, spring and summer. Nominally this occurred around 1246 CE (*i.e.*, when the ecliptic longitude of perihelion was the same as that of the winter solstice, 270°; *cf.* Table 1).

Since that time perihelion has advanced by more than 13 days, now generally occurring after the middle of the first week of the calendar year. In about 1,800 years' time perihelion will have progressed by another 31 days into the very middle of boreal winter (or austral summer), which will then be as short as it can be; while northern summer (straddling aphelion) will attain its longest possible value; and spring and autumn will have equal (intermediate) durations in each hemisphere.

Here I have calculated the insolation changes across centurial intervals as a function of latitude and time of year in different epochs within the past five millennia, predicated on an assumption that the intrinsic shortwave radiation output of the Sun has indeed been constant. I used a semi-major axis (a) for Earth's orbit of precisely one astronomical unit (AU), and therefore a period of one Gaussian year (365.256898 days) as the length of the year. Year numbers are stated only as indicators of an epoch, rather than coinciding precisely with the years on *any* calendar: religion-based calendars can cause confusion when seasonal changes are being investigated (Steel 2000; Sagarin 2001).

Using relevant parameters (a=1 AU, and e, ε, $\tilde{\omega}$ as in Table 1) for each epoch I divided Earth's orbit into arcs each one-thousandth of a Gaussian year in duration (*i.e.*, about 0.365 days), registering the vernal equinox (*i.e.*, when the Sun ascends through the celestial equator) to be at the start of day-of-year (DOY) 80. In this way the orbits for each epoch are identically-phased with reference to that equinox (Joussaume and Braconnot 1997), perihelion passage occurring at a longitude ($360^{\circ} - \tilde{\omega}$) earlier (*vide* the final column in Table 1 for the equivalent DOY). [Advance warning is necessary here of a discussion appearing later in this paper: the choice of reference point on the ecliptic can affect the outcome of the calculations, as discussed

---

* It does actually change, very slightly, due to the non-sphericity of the Earth.

by Joussaume and Braconnot (1997); there is no 'correct' choice, and by default I have used the vernal equinox as that reference point, in accord with their recommendation.]

Using a solar constant of 1360 W/m² (Kopp and Lean 2011) I next computed the incoming solar radiation flux at the top of the atmosphere (TOA) above nine latitudes (Φ) in 20° steps from 80°S to 80°N. Differences between the computed insolations for different epochs calculated for each intra-annual time step then show how the insolation has changed, as a function of both time-of-year and latitude.

The magnitude of the insolation changes

The year 1750 is conventionally taken as a reference epoch prior to the start of the Industrial Revolution and the concomitant enhanced emission rate of carbon dioxide through human activities. By subtracting the computed insolations for 1750 from those for 2000 I derived Figure 1. The amplitudes of the changes in the incoming solar flux are seen to be of order 1–2 W/m², the highest positive peaks being slightly above 1 W/m².

For comparison, in the most recent *Synthesis Report* of the Intergovernmental Panel on Climate Change (IPCC 2007) the net radiative forcing due to human activities since 1750 CE is estimated to be about 1.6 W/m², the only natural forcing listed therein being a solar irradiance increase estimated at 0.12 W/m². On that basis the insolation changes as a function of latitude, time-of-year and epoch as presented here appear to be significant. Note that almost all of the computed changes are due to the precession of perihelion; the slight alterations of e and ε over a century or two have negligible effect.

The reader should recognise that the forcings cited above from the *Synthesis Report* (IPCC 2007) might be regarded as being across-the-year values, whereas the forcings I have calculated are intra-annual changes between two epochs. An annual averaging of my computed insolation forcings might render a value near zero for any particular latitude, but their importance stems from their distinct phasings within the annual cycle: increased insolation in spring at high northern latitudes must result in enhanced ice and snow melting and any subsequent small reduction in insolation across summer and autumn would be outweighed by a rather greater fraction of the incoming solar flux being absorbed rather than reflected back into space by dint of the reduced albedo inherent in open (rather than ice-covered) sea and land.

Insolation changes over centuries at different epochs

In Figure 2 I have plotted the insolation changes over four distinct centurial intervals: (a) 1900 to 2000 CE; (b) 1200 to 1300 (*i.e.*, bridging the mid-13th century epoch when perihelion was aligned with the winter solstice); (c) 0000 to 0100 (*i.e.*, 1 BCE to 100 CE); and (d) From –3000 to –2900.

If one compares Figure 2(b) for the years 1200 to 1300 with Figure 2(a) for the past century, although a global trend for an increase in insolation in the first half of the year and a reduction in the second half is apparent, near-symmetry between corresponding northern and southern latitudes is seen in the earlier interval but not in the later/more recent one. This implies that the rate of change of insolation is accelerating in the NH in the present epoch, but decelerating in the SH. For example, the area under the 80˚N curve between DOYs 70 and 160 is about 17 percent higher in Figure 2(a) than in Figure 2(b).

Next I examine an interval further back in time (*i.e.*, well before the perihelion-solstice alignment around 1246 CE). The latitude-dependent insolation changes between years 0 and 100 plotted in Figure 2(c) indicate that the amplitudes of the changes that occurred more than 1,900 years ago were greater in the SH than the NH. The area under the 80˚N curve between DOYs 70 and 148 is about 62 percent higher in Figure 2(a) than in 2(c), with continued insolation enhancement between DOYs 148 and 165 in Figure 2(a) as compared to an insolation *decrement* across the same DOYs in Figure 2(c).

The NH versus SH contrast was greater still in earlier periods. The change between epochs –3000 and –2900 is shown in Figure 2(d), with the insolation change at high northern latitudes in the first half of the year being negative, as might be anticipated due to perihelion passing the longitude of the autumnal equinox 6,000 years ago (*i.e.*, around year –4000).

A comparison of Figures 2(c) and 2(d) leads to an expectation that the NH received progressively less insolation in spring (and so less ice melting) until between three and four millennia ago, from which time the far northern spring insolation has increased, slowly at first but in an accelerating manner over the past handful of centuries, from a comparison of Figures 2(a) and 2(b).

A natural question to ask would concern how large the insolation changes (in W/m^2) are as compared to the actual insolations: by what fraction are they changing? In Figure 3 I show the percentage changes between 1900 and 2000 (*i.e.*, the same data as in Figure 2(a) but expressed as fractional changes). These indicate that there has been an increase of order 0.1% at all northern latitudes across spring (and recall that this is the increase during just one century). Also notable are the higher-amplitude peaks evidenced at both 60˚N and 60˚S during their respective winters. The reader would be correct to presume that, should I have plotted also the curves for (say) 65˚ or 70˚ north and south, even larger peaks (although of short duration) would have been seen.

Inspection of the four panels in Figure 2 shows that all curves are shifting to the right as the time is progressing, in accord with the direction of perihelion precession. For example, in Figure 2(b) the peak for 80˚N occurs during DOY 122, whereas in Figure 2(a), seven centuries later, it occurs during DOY 126. The curves in Figure 2 therefore demonstrate variations both in amplitude and in phase, another manifestation of the seasons changing their characteristics over centurial/millennial timescales due to perihelion precession.

An implication of this is that simplistic calculations of insolation changes over intervals of a millennium and more can be misleading should the intent be an understanding of climate change: whilst the subtraction of one set of insolation data for one epoch from another substantially separated in time (*i.e.*, by millennia) might well indicate the distinctions between the instantaneous insolation parameters, the path taken between them may well not be linear and so could be misunderstood, with the way in which climate change has actually occurred then being obscured.

Climatic consequences for the present

The ongoing perihelion precession since the mid-13th century in particular has resulted in small but definite year-on-year enhancements of insolation in the NH during spring (see Figures 2 and 3). One obvious outcome to be anticipated is faster spring melting of the Arctic ice, resulting in a greater amount of open sea than in preceding decades and centuries, and also less snow and ice cover on land. Across summer (and early autumn) the resultant lowered average albedo must cause enhanced absorption of solar energy (and so warming), despite the insolation during that season lessening slightly from one year to the next: the effect of a reduction in albedo from (say) 0.8 to 0.4 is an increase in the absorptivity by a factor of three, so that the comparatively tiny reduction in summer insolation is of little consequence. Reduced NH ice formation would then occur over winter, and so there is less to melt the following spring, and so on: a gradual feedback effect persisting for multiple centuries or even millennia.

To make clear the trend in insolation change that is the core matter here, in Figure 4 I have plotted the change in insolation between the years 1246 and 2013 as a function of time of year at 65°N only. This latitude was chosen because it is close to the Arctic Circle and is mostly occupied by land masses, and was recognised by Milutin Milankovitch to be a pivotal zone with regard to the control of the global climate under changes in Earth's orbit and obliquity. Researchers have continued to use it as a benchmark latitude. Figure 4 shows clearly how the insolation at 65°N has changed between the year 1246 (when perihelion and winter solstice were aligned) and the present time. In late April and early May the enhancement across those 767 years exceeds 2.8 W/m^2, 75 percent higher than the net AGW component of 1.6 W/m^2 estimated by the IPCC (2007).

It has not escaped my notice that this enhanced spring insolation at high northern latitudes, coupled with positive feedback across summer due to melted snow and ice and so reduced albedo, would produce gradual global or at least hemispherical – not just regional – warming over the centuries during which it has been slowly increasing.

In the SH the phasing of the insolation changes is different. At far southern latitudes the insolation has *reduced* during austral spring across the past several millennia (see Figure 2), implying an expectation of progressively *reduced* melting of sea ice in that season, and so an *increase* in the mean albedo of the ocean surrounding the Antarctic continent. The feedback effect in the Antarctic is therefore to the contrary of that in the Arctic: more sea ice, and so elevated albedo, and so increasing sea ice, in the absence of any other influences (such as AGW, energy transport through the atmosphere, ocean currents, *etcetera*). In austral summer the insolation so far south is now higher than over the past several millennia, but the insolation enhancements at that time of year are decelerating (compare the four panels in Figure 2); and that insolation is impinging on a high-albedo surface.

This is consistent with the established (but heretofore puzzling) dichotomy in the melting behaviour of Arctic and Antarctic sea ice (Schiermeier 2012; Shepherd *et al.* 2010; Parkinson and Cavalieri 2012), with the NH ice disappearing whilst the SH sea ice is gradually growing.

The fact that the Antarctic sea ice *is* growing in extent may be interpreted as evidence for the changing insolation (the CIT) actually dominating the AGW: if the influence of the AGW were greater than that of the falling spring insolation in far southern latitudes then *a priori* one would expect the amount of sea ice to be reducing in the Antarctic; and it's not.

Effect of altering the reference point on the ecliptic

Earlier in this paper I foreshadowed the importance of the work of Joussaume and Braconnot (1997) on how the choice of reference point on the ecliptic for registering pairs of years in different epochs can affect the values for the changes in insolation that are derived. Here I give a straightforward example of the pitfalls that may be encountered.

In Figure 1 were presented plots showing how the insolation at different latitudes had changed between the years 1750 and 2000, predicated on the years being commonly registered with the vernal equinox occurring at the start of DOY=80. In Figure 5 I have repeated the calculations with the reference point on the ecliptic now being the autumnal equinox, which was fixed at DOY=266.45; the precise numerical value is unimportant except in shifting the curves sideways in the plot.

It is obvious that Figures 1 and 5 differ in various respects. The biggest contrasts between the two are seen for the extreme latitudes (80°N and 80°S). At all other latitudes the trends remain much the same. Thus although little faith should be placed in the precise values of the calculated changes in insolation, the general sense of how the insolation is altering at different latitudes and at different times of year seems to be firm.

Nevertheless this is a potentially-unrecognized deficiency in some published research results of which climate scientists should be aware. To obtain a better understanding of what comparative insolation calculations mean, and do not mean, a detailed understanding of the paper by Joussaume and Braconnot (1997) is highly-recommended to all working on climate change research.

Why has this insolation phenomenon been hitherto overlooked?

The increasing Arctic spring insolation phenomenon, and hence its consequences, seems quite straightforward and yet apparently it has been overlooked until now. Why might this be the case? One major factor appears to be a disconnect between the climate change community and the small astronomical contingent who perform the calculations of orbital variations and concomitant insolation changes, this group having been metaphorically led for some decades by the estimable André Berger. It is apparent that various members of the climate change community have used insolation values derived from Berger's publications without first developing a critical understanding of what those insolation values actually mean. It seems that Berger is aware of this; for example, the Paleoclimate Modelling Intercomparison Project (PMIP) Phase II team has noted[†] as follows: "*André Berger has warned us about the various approximations used by the GCMs that may induce differences in insolation that are not negligible with respect to the Milankovitch forcing*."

[†] `http://pmip2.lsce.ipsl.fr/design/boundary.shtml`

The possible role of orbital changes has received comparatively limited emphasis in studies of how the climate has varied over recent centuries. For example, the Fourth Assessment Report (FAR) of the IPCC (Jansen *et al.* 2007) states that "*…although [orbital] forcing is incorporated in most models, its impact on climate can be neglected compared to the other forcings*," and references a sensitivity study by Bertrand *et al.* (2002); note that Bertrand *et al.* (2002) includes Berger as an author. Immediately following that statement is Figure 6.13 of the FAR (Working Group I: Physical Science Basis), in which are plotted adopted radiative forcings and resultant temperature simulations in twelve published models, of which only one (that by Tett *et al.* 2007) incorporates orbital forcing. Tett *et al.* state:

> ***Orbital forcing:*** *Changes in the orbital parameters following Berger (1978) were used to change the top of atmosphere (TOA) insolation.*

Tett *et al.* (2007) apparently used the epoch-dependent insolation averaged over the months of the NH summer (taken to be June, July and August [JJA] in that paper) to derive changes in TOA insolation between epochs. This is an approach used in many research publications, and it is fundamentally incorrect and misleading. Calendar-monthly averaging might be regarded as rather literally being an analysis of moving feasts, in that the phasing of the months follows the Gregorian calendar's bissextile year rules, and that calendar was established in order to facilitate the Easter computus rather than to regularise the seasonal cycles (Steel 2000; Sagarin 2001). Any such averaging obscures the actual insolation changes occurring between instants that reflect the same phasing within a year (*e.g.*, identical time intervals after the vernal equinox: Joussaume and Braconnot 1997).

First example of how things can go wrong

A recent example of how things can go wrong is a paper published in *Nature Geoscience* by Pike *et al.* (2013). These authors refer to "*December insolation*" and "*peak summer insolation at 60°S*" over the past 12,000 years, taking values from a paper by Berger and Loutre (1991). Those values are what Berger refers to, in his various publications, as "*mid-month*" values, which the reader might assume to imply insolation values around the middle of each calendar month. In fact each of Berger's insolation values pertain to that when the Earth attains ecliptic longitudes spaced in consistent 30° steps from a vernal equinox assumed to occur at the start of day number 80 in each year (*cf.* my earlier comments, and the paper by Joussaume and Braconnot 1997). In fact, it is perihelion precession (the dominant factor causing TOA insolation changes on centurial time scales) itself that causes these junctures (the 30° steps in ecliptic longitude) to vary their temporal spacing!

The values that Berger tabulates for 'December' therefore are specific to an ecliptic longitude of 270°, which is the instant of the winter solstice (or, here, the austral summer solstice given that Pike *et al.* (2013) are dealing with the Antarctic climate). That instant marks the beginning of the austral summer; and, although the insolation peak may well occur close to the solstice, in general the two do not precisely coincide. As aforementioned, in terms of the DOY the solstices and equinoxes shift by several days over millennia, due to perihelion precession.

Further, Pike *et al.* (2013) state that "*The oceanic proxies respond strongly to spring insolation (peak 8.0–6.0 kyr…)*" and reference Berger and Loutre (1991) again. That paper by Berger and Loutre does not contain any values for the austral spring insolation.

Second example of how things can go wrong

I now turn to another publication as an example of how changes in insolation might be miscalculated. Bradley *et al.* (2003), in section 6.11.1 of their book chapter, discuss latitude-dependent insolation changes on a month-by-month basis over the past 10,000 years (their Figure 6.21) and the "last millennium" (their Figure 6.22), but do not mention a source for their data. I note in particular that contained in Figure 6.22 of Bradley *et al.* (2003) are features that differ strongly from my own calculations. A specific and important point is that their Figure 6.22 shows no marked increase in insolation across spring at far northern latitudes, which has been identified in this paper (*e.g.*, Figure 4) as being a plausible root cause of part of the observed global warming over the past two centuries. Therefore I have sought to discover the source of Bradley *et al.*'s data, and the form of the analysis leading to their Figure 6.22.

Bradley *et al.* (2003) have, elsewhere in their chapter, made use of 'mid-June' and 'mid-December' insolations from Berger and Loutre (1991), and I have highlighted earlier the danger in assuming that these pertain to precisely the same times of year in different epochs; they don't. The paper by Berger and Loutre, however, does not contain the data that Bradley *et al.* (2003) plotted in their Figures 6.21 and 6.22. Mid-month (again, meaning in steps of 30° in ecliptic longitude) values of insolation at different latitudes were published by Berger in an earlier paper (Berger 1978), though, and values are available from various sources on the internet[‡]. It seems feasible that Bradley *et al.* (2003) have used those data, although I note that Berger's output was based on 'the present' being 1950 CE, and works backwards in one-millennium steps so that his preceding set of data pertained to 950 CE (*i.e.*, not the "last millennium" of Bradley *et al.* 2003). I further note that Berger's insolation values were output as integers, which is precise enough if the insolations are some tens or hundreds of W/m^2, but if the insolation *changes* from one epoch to another are only a few W/m^2 (as is the case) then floating-point output is necessary for the calculated differences in insolation to be sensible.

Using Berger's program

André Berger generously makes his FORTRAN program available on his FTP site at l'Université catholique de Louvain[§] and so I have downloaded it and made the conversion to floating-point rather than integer output. He uses a registration of the vernal equinox at DOY=80, as have I. Using the program option to calculate Berger's 'mid-month' (30° steps in ecliptic longitude) insolations I derived values for the same set of latitudes as I have generally used (80°S to 80°N

[‡] For example, see: `http://www.ncdc.noaa.gov/paleo/forcing.html`
Specifically, go to `ftp://ftp.ncdc.noaa.gov/pub/data/paleo/insolation/`
and access files `bein1.dat` and `contents.78`

[§] ftp://ftp.elic.ucl.ac.be/berger/

in 20° steps) for 1950 and 950 CE, and then obtained the differences between them. The results are shown in Figure 6(a). The curves shown there have been included simply to guide the eye between the points plotted for each latitude, those points being the discrete output results.

The same set of data is also shown in Figure 6(b), except that now the abscissa is the DOY as I have used elsewhere in this paper. This means that the points are *not* equally spaced along the abscissa: what I have done, for each 30° step in ecliptic longitude, is to take the average of the different fractional DOY values for the years 950 and 1950, and used those average DOYs in plotting the points. That averaging, however, is not a valid analytical step: the differences in ecliptic longitudes in 950 and 1950 as a function of DOY varies pseudo-sinusoidally, with the ecliptic longitude in 1950 being a maximum amount ahead of that in 950 by about 0.7 degrees near the summer solstice, and a maximum trailing amount of about 0.5 degrees near the winter solstice. One might argue, therefore, that the points are *incorrectly* plotted in that their meaning is obscure, because they were calculated on the basis of a tacit (but, it seems, often unrecognised) assumption that the ecliptic longitudes of Earth in 950 CE occurred at the same times-of-year as the identical ecliptic longitudes in 1950 CE, and that assumption is false.

A comparison of Figures 6(a) and 6(b) with Figure 6.22 of of Bradley *et al.* (2003) leads me to suggest that either they have analysed and plotted the data from Berger (1978) in this way, or else they have done something very similar.

To obtain Figure 6(c) I again used Berger's FORTRAN code, but altered it such that it output the insolations on a day-by-day basis for a 365-day year in both 950 and 1950 CE. With this higher time resolution (single-day jumps from DOY=80) a rather different set of curves for the insolation change between 950 and 1950 CE is obtained.

Finally in Figure 6, I calculated the insolation changes between 950 and 1950 using my own software, to derive Figure 6(d). It is apparent that this is essentially identical to Figure 6(c), the only noticeable difference being that because I calculate the insolations every 0.365 days rather than just once per day the curves in Figure 6(d) are smoother than in Figure 6(c).

To summarise the outcome of the deliberations leading to Figure 6: climate change researchers can certainly use Berger's FORTRAN program to derive insolation values in different epochs, but if they wish to derive insolation *changes* then it is necessary to use equal *time-steps* rather than equal jumps in ecliptic longitude, and suitable time resolution is also required. Because the change in insolation at the same time of year in epochs separated by a millennium is typically only the same as the change from one day to the next in the same year, the time-steps should be less than a day, as I have used.

Third example of how things can go wrong

The first two authors of Bradley *et al.* (2003) are also co-authors of the later paper by Kaufman *et al.* (2009). Therein it is stated that "Over the past 2000 years, summer (JJA) insolation at the top of the atmosphere decreased by about 6 W/m^2 at 65°N", followed by a citation of the paper by Berger and Loutre (1991). Figure 3F of Kaufman *et al.* (2009) shows a downward-trending line for the change in insolation at 65°N, and although the abscissa is labelled 0, 4 and 8 W/m^2 the start of the line is consistent with their stated "about 6 W/m^2". It is not clear whether the abscissa is plotted correctly (*i.e.*, whether the values are for years 0 and 2000, or –50 and 1950 in accord with the calculations presented by Berger and Loutre 1991).

In fact Berger and Loutre (1991) do not give values of insolation at 65°N for all of JJA, but only for 'mid-month' July (*i.e.*, actually for ecliptic longitude 120°, and I have indicated above the problem inherent in using insolation values for identical ecliptic longitudes in different epochs in attempting to assess the change in insolation over the interval between). Thus the reader does not know the source of data employed by Kaufman *et al.* (2009). The mid-month July (*i.e.*, ecliptic longitude 120°) insolation values from Berger and Loutre (1991) are 426.76, 430.12 and 434.69 W/m^2 for the years 1950, 950 and –50 respectively, indicating a decrement in insolation *at this ecliptic longitude and at geographical latitude 65°N* of nearly 8 W/m^2 over this two-millennium interval.

In Figure 7 I present my own calculations of the insolation changes between the years 0 and 2000 for latitudes 80°S to 80°N in 20° steps. Interpolating from this plot, for 65°N at the start of June (DOY=152) the change in insolation is about +2 W/m^2; at the start of July (DOY=182) the figure is approximately –6 W/m^2; at the start of August (DOY=213) the figure is around –11 W/m^2; and at the end of August (DOY=243) the figure is about –9 W/m^2.

In view of this it is not clear what useful meaning an average value across JJA might have. One could imagine a situation whereby June and July have much-reduced insolations (and so limited snow/ice melting is caused) followed by an August with elevated insolation impinging on ocean and terrain with high albedo, and yet in another epoch precisely the same average JJA insolation occurs but distributed with June having the higher insolation (and therefore more melting) followed by July and August with lowered insolations, the sunlight then falling on sea and land with lower mean albedo and so greater absorptivity. The average insolation (or insolation change) over an extended intra-year period, especially a human construct such as calendar months, could be very misleading in terms of the control of the climate.

Scientific philosophy and process

Due to the fact that the CIT as outlined here is very simple, and the existence of the increase in insolation in NH spring is inarguable, and also because this hypothesis is able to explain the phenomena mentioned in the Introduction to this paper whereas the AGW hypothesis alone does not, Ockham's razor dictates that the CIT should be adopted as a working hypothesis for global climate change.

The CIT may be tested by various means, including:

a. Examination of past climate records and proxies (*e.g.* Arctic ice extent and thickness over the past millennium or so);

b. Comparison with future climate behaviour; and

c. Simulation of the past and present climate through year-by-year evolutionary models starting at least a millennium in the past and including latitudinally-dependent insolation values and estimates of albedo changes under progressive gain or loss of polar snow and ice.

The albedo of sea ice with a covering of snow is much the same whether that ice be one or a hundred metres thick, and so it might be that the ice had been thinning for many years before the acceleration in the rate of spring insolation increase in the NH started in the mid-13th century, eventually leading to the sea ice breaking up and its melting being hastened, with the feedback effect of reduced albedo then resulting in overall warming.

The role of rising levels of anthropogenic greenhouse gases since the Industrial Revolution in causing some elevation in global temperatures is not denied herein. Rather, the measured temperature rise coupled with other observed phenomena (melting Arctic ice, growing Antarctic sea ice) are suggested to be due to the combination of AGW and CIT but with the latter being dominant. Nevertheless it seems likely that the rate of spring ice melting in the far northern latitudes has been bolstered significantly by AGW over the past 100–200 years, the combination of the two contributions (CIT and AGW) resulting in the rapid and extensive melting witnessed over the past few decades.

One could ponder what the likelihood might be of those two effects occurring in concert at the present time. Given that perihelion passed the ecliptic longitude of the winter solstice only seven or eight centuries ago, moving into boreal winter and causing accelerating increases in northern latitude spring insolation over the past several centuries, the *a priori* probability (of this coinciding with increasing human emissions of carbon dioxide *etcetera*) is small, assuming no causal relationship (*i.e.*, assuming that the rise of our scientific/industrial civilisation is not connected with climate change provoked by perihelion precession). The *a posteriori* probability, however, is unity: this is the way things are.

To add to this coincidence, note that the way in which the increase in spring insolation at high northern latitudes in recent centuries has been overlooked until now also stems from the influence of the precession of perihelion into boreal winter: inspection of Figures 6(b) and 6(c) indicates that the biggest underestimates of insolation changes occur at high latitudes, and this is due to perihelion precession shifting the time-of-year of particular ecliptic longitudes, those longitudes having been erroneously employed in various publications as instants suitable for the comparison of insolation values within years at different epochs.

We should not expect linearity in climate behaviour over the past millennium: the Mediaeval Warm Period and the Little Ice Age show the fallaciousness of any such expectation. However, simple yet viable explanations for observed phenomena should not be ignored. Such an explanation/hypothesis has been outlined herein.

Table 1 | Values used for the eccentricity, obliquity, and longitude of perihelion.

Epoch	*Eccentricity* (*e*)	*Obliquity* (ε, degrees)	*Longitude of perihelion* (ϖ̃, degrees)	*DOY of perihelion (for vernal equinox at DOY=80)*
2013	0.016698	23.4381	283.118	3.88
2000	0.016704	23.4398	282.895	3.66
1950	0.016724	23.4463	282.039	2.80
1900	0.016744	23.4528	281.183	1.94
1750	0.016804	23.4723	278.616	364.61
1300	0.016982	23.5306	270.927	356.86
1246	0.017003	23.5376	270.005	355.92
1200	0.017021	23.5435	269.221	355.13
0950	0.017116	23.5757	264.960	350.81
0100	0.017430	23.6830	250.515	336.09
0000	0.017466	23.6954	248.820	334.36
−2900	0.018383	24.0118	200.034	283.70
−3000	0.018410	24.0208	198.364	281.94

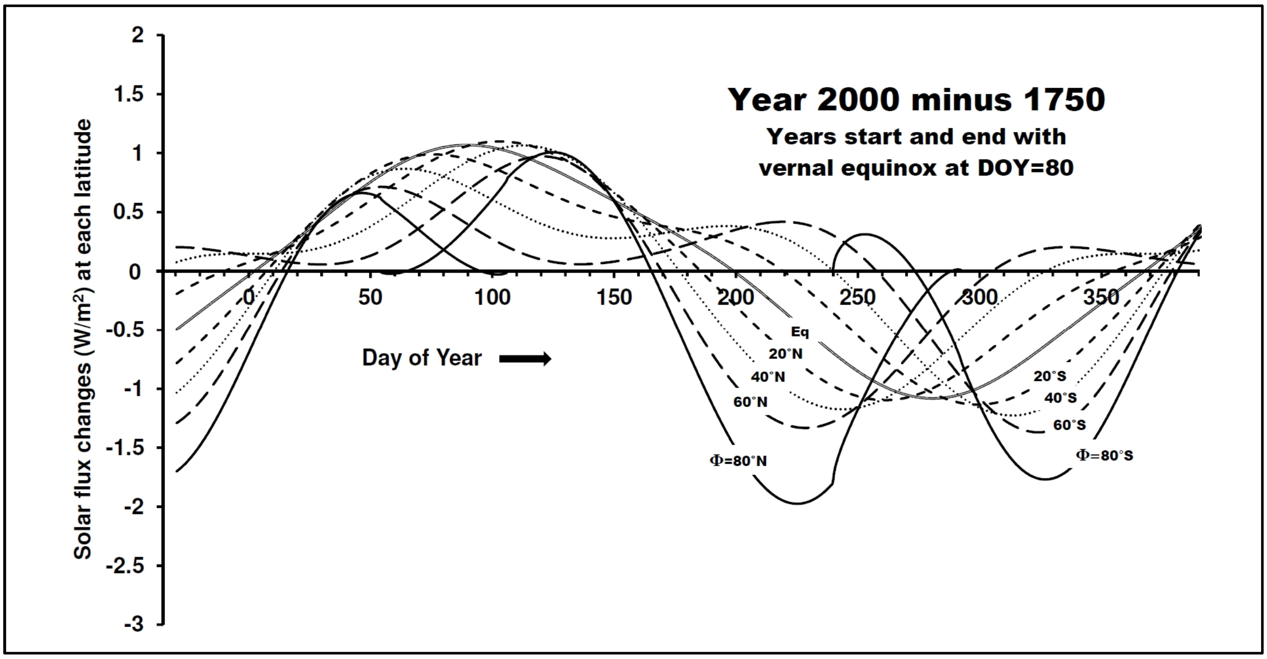

Figure 1 | Latitude- and day-of-year-dependent insolation changes between the years 1750 and 2000 CE.

Each year was assumed to have a duration of one Gaussian year and was split into a thousand equal-length time steps, with the years starting and ending with the vernal equinox registered to be at the beginning of day-of-year (DOY) 80. In order to produce wrap-around at the start and end of the year 1,161 instants are plotted.

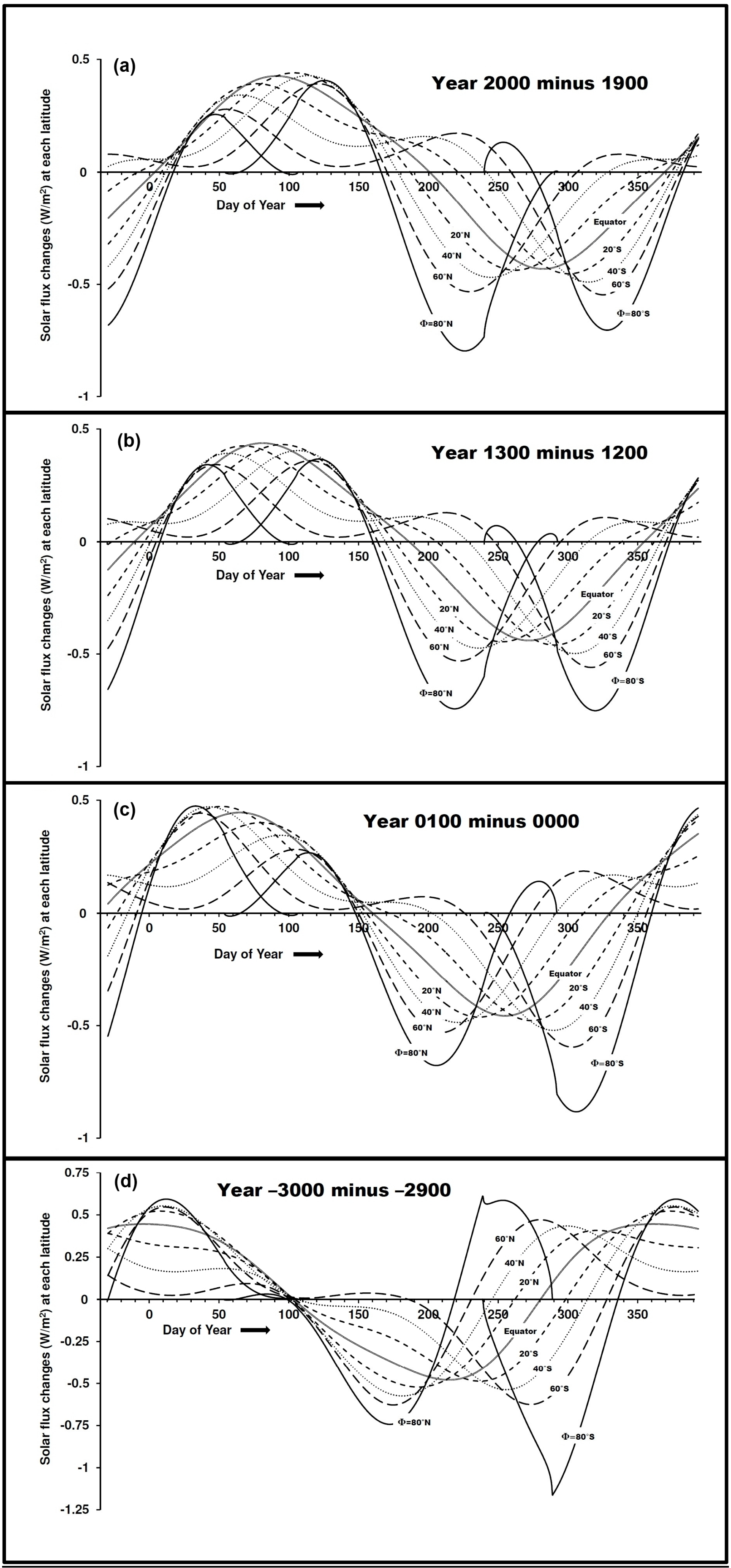
(a)
Year 2000 minus 1900
(b)
Year 1300 minus 1200
(c)
Year 0100 minus 0000
(d)
Year –3000 minus –2900
Solar flux changes (W/m²) at each latitude
Day of Year
Equator
20°N
40°N
60°N
Φ=80°N
20°S
40°S
60°S
Φ=80°S

Figure 2 | Insolation changes over intervals of one century in different epochs.

(a) The change in solar flux from 1900 through to 2000 at different latitudes. Each year is registered such that the vernal equinox is at the start of day 80. Although the abscissa is labelled ‘Day of Year’, actually the time steps are one-thousandth of a Gaussian year.

(b) As in panel (a) except for the interval between 1200 and 1300 CE, bridging the epoch in which perihelion was last aligned with the winter solstice.

(c) As in panel (a) except showing the change in solar flux at the top of the atmosphere across the century between the years 0000 (*i.e.*, 1 BCE) and 0100 CE.

(d) As in panel (c) except for the interval from –3000 (*i.e.*, 3001 BCE) to –2900.

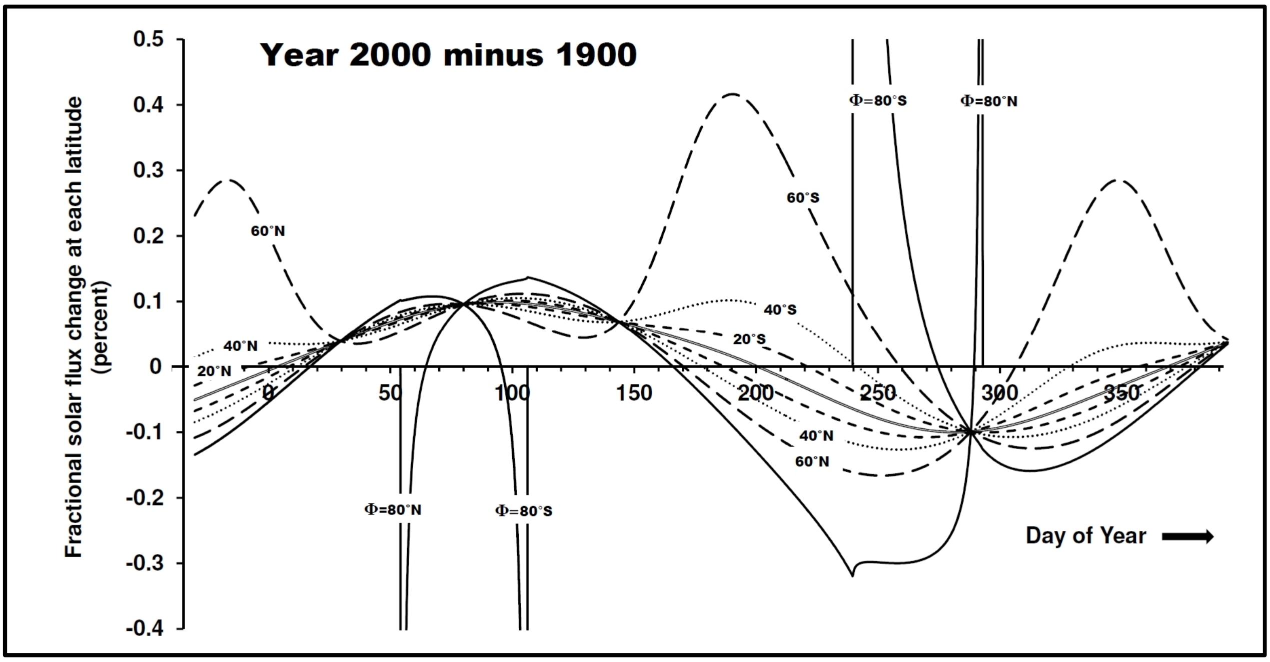

Figure 3 | Fractional insolation changes between the years 1900 and 2000.

This diagram contains the same data as in Figure 2(a) except that here the insolation changes are plotted as a percentage of insolation at each latitude and each DOY. The broad maxima centred on DOY=190 for 60˚S and on DOY=350 for 60˚N are indicative of milder winters far from the equator. The main point of interest here is the increased insolation at all northern latitudes across spring (from DOY=65 to 165) which will cause greater snow and ice melting, decreasing the albedo and making the subsequent reduction of insolation across summer and autumn (DOY=170 to 350) inconsequential. No such springtime insolation increase occurs in the far southern latitudes, the increased insolation in austral summer and autumn (DOY=15 to 170, and thereafter for 60˚S) impinging on sea ice that has not been subject to enhanced warming earlier in the seasonal year. It is emphasized that this diagram pertains only to the change across a single century.

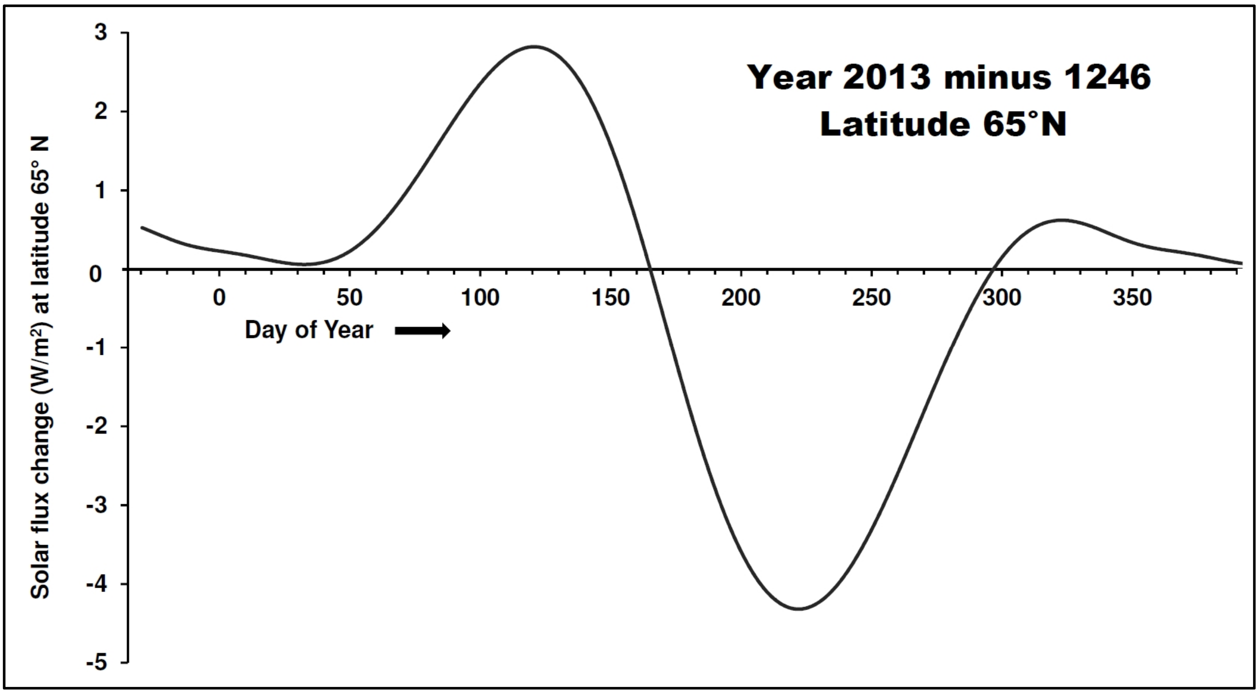

Figure 4 | The change in insolation at latitude 65°N between years 1246 and 2013.

The enhanced insolation across spring must be prompting more rapid and more extensive melting of the snow and ice cover at this near-polar-circle latitude, reducing the albedo and thus increasing the absorptivity of the region. This then leads to elevated absorption of solar radiation across summer and early autumn despite the reduced influx across those seasons indicated in this plot.

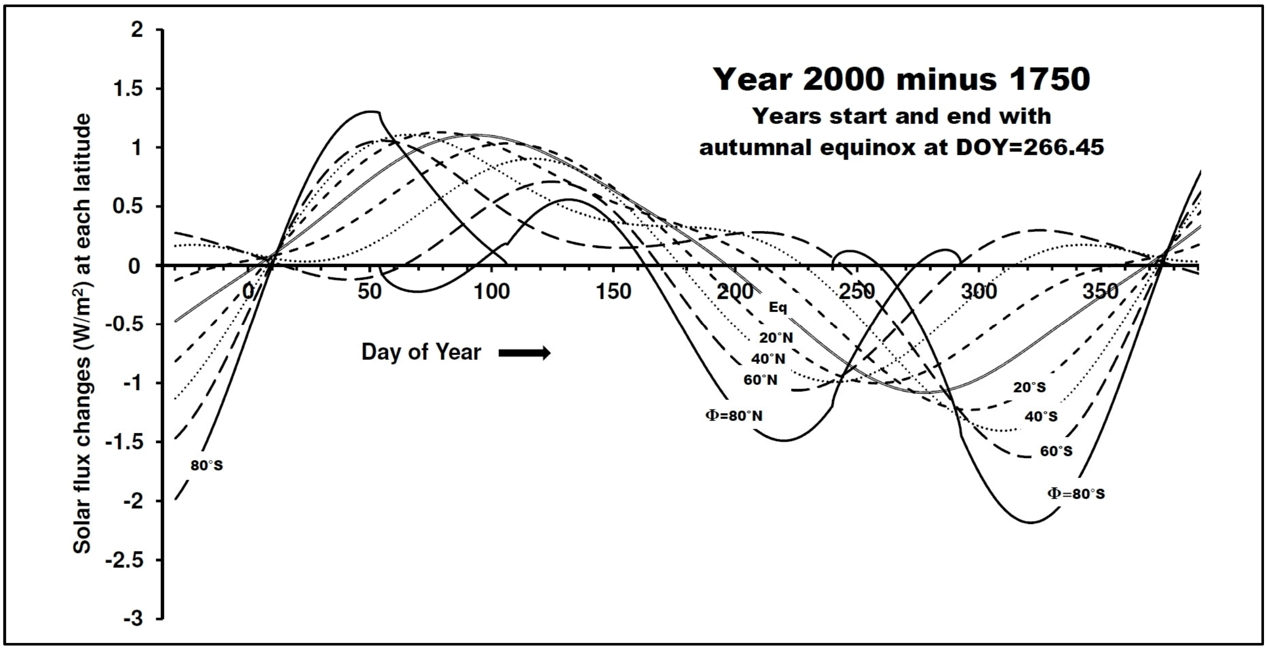

Figure 5 | Insolation changes between 1750 and 2000 based on fixing the autumnal equinox at day-of-year 266.45.

All previous plots have been based on fixing the *vernal* equinox at DOY=80, whereas here the *autumnal* equinox has been placed at DOY=266.45 for each of the two years in question. This Figure 5 should be compared with Figure 1, which was derived for the same pair of years but registered them against each other at the vernal equinox, as discussed and recommended as a standard by Joussaume and Braconnot (1997).

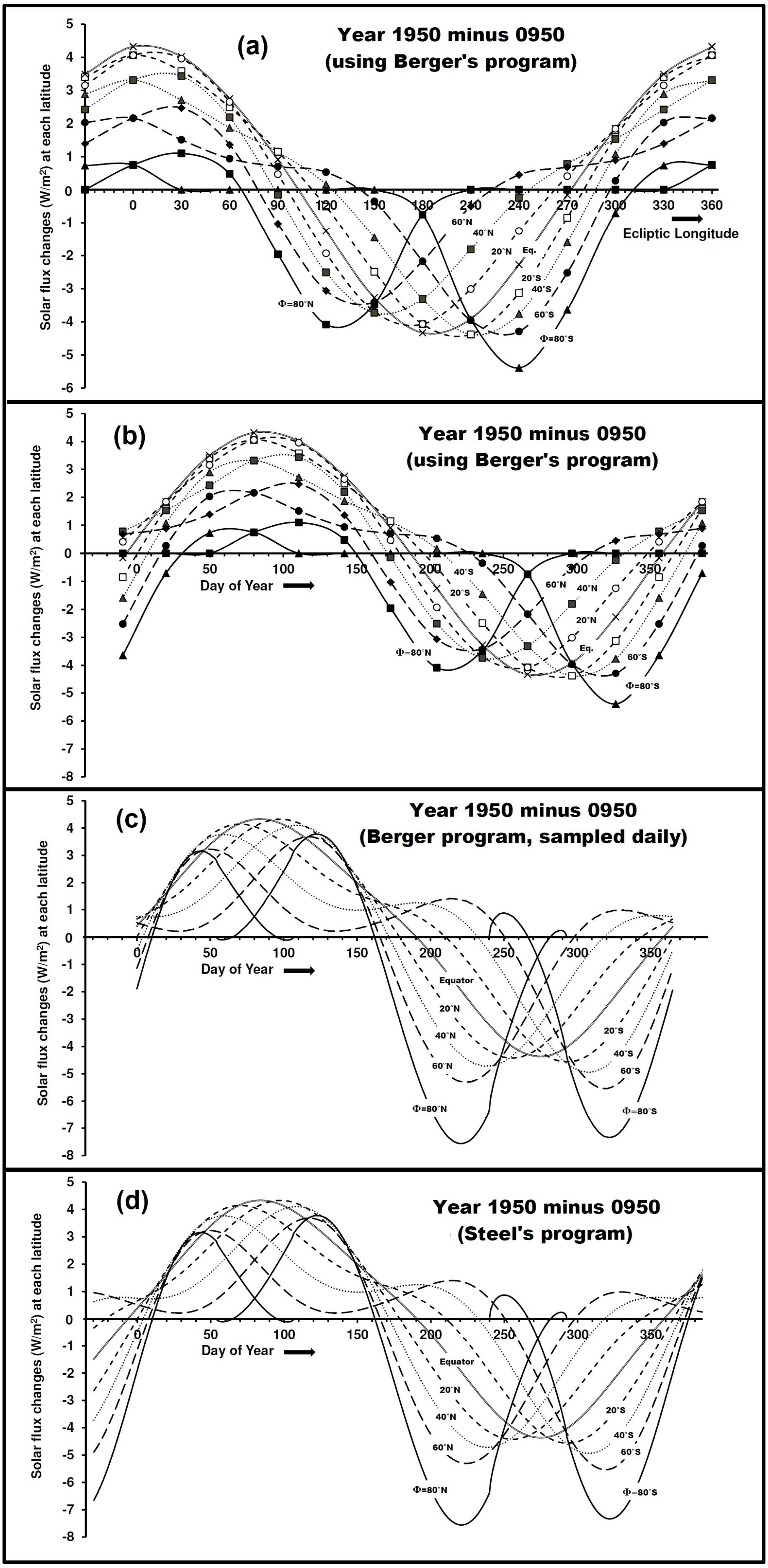
(a)
Year 1950 minus 0950
(using Berger's program)
Solar flux changes (W/m2) at each latitude
Ecliptic Longitude
Φ=80°N
60°N
40°N
20°N
Eq.
20°S
40°S
60°S
Φ=80°S
(b)
Year 1950 minus 0950
(using Berger's program)
Day of Year
(c)
Year 1950 minus 0950
(Berger program, sampled daily)
Equator
(d)
Year 1950 minus 0950
(Steel's program)

Figure 6 | Insolation changes between 950 and 1950 derived by different methods.

(a) The change in solar flux based on calculating the insolation as a function of ecliptic longitude in each epoch using the FORTRAN program of Berger (1978), and then taking the difference between them; note that the parameter plotted on the abscissa in this Figure 6(a) is the ecliptic longitude, not the day-of-year as in the three plots below.

(b) As in (a) except that the insolation differences are now plotted as a function of the day-of-year (DOY); see the main text for an explanation of why the conversion from constant ecliptic longitude values in each epoch to this averaged DOY is an invalid analytical step leading to misleading results.

(c) Insolation differences again based on output from Berger's program, but now computed using equal time steps of one day across a 365-day year.

(d) Output from my own software coding, with time steps of slightly more than 0.365 days (one-thousandth of a Gaussian year).

The agreement between (c) and (d) verifies their outputs. These differ very substantially from the results plotted in (a) and (b) because the process of taking the differences between insolations calculated for the Earth at equal ecliptic longitudes in separated epochs is invalid.

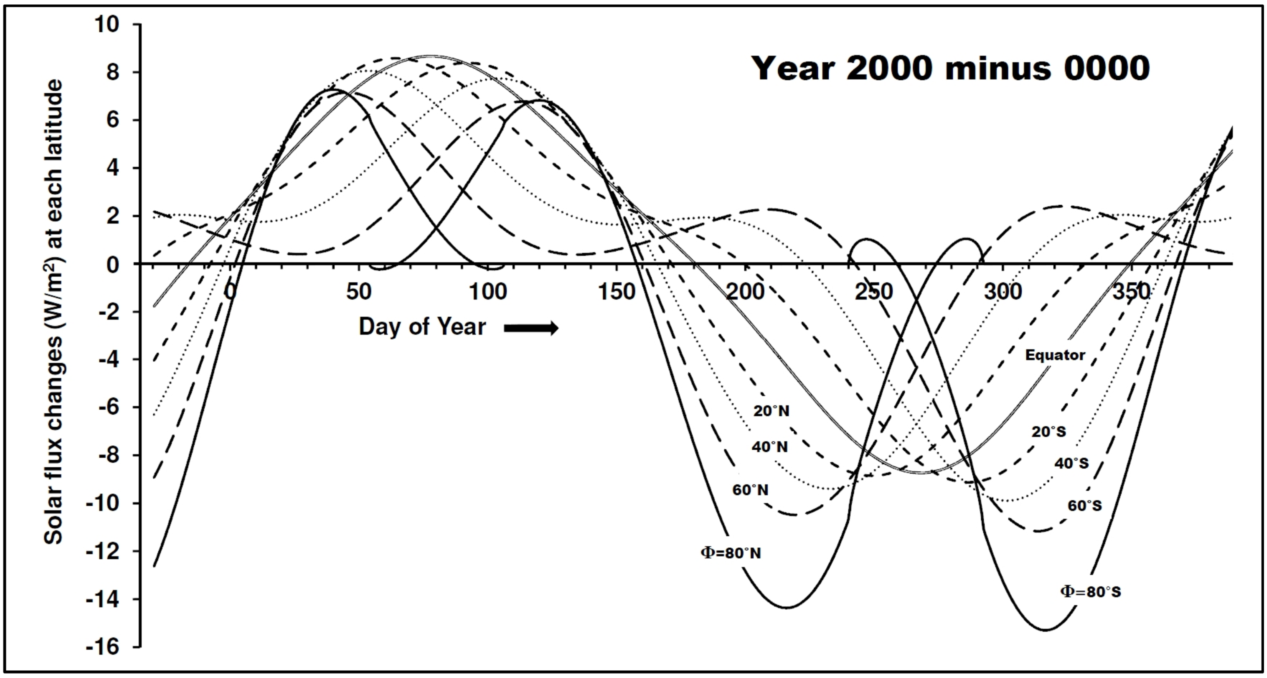

Figure 7 | Latitude-dependent changes in insolation over the past two millennia.

The results plotted here should be compared with the purported change in insolation over the same two-millennium interval for June, July and August as presented in Figure 3F of Kaufman *et al.* (2009).

References

Berger A 1978 *J. Atmos. Sci.* **35** 2362–2367.

Berger A and Loutre M-F 1991 *Quat. Sci. Rev.* **10** 297–317.

Bertrand C *et al.* 2002 *Tellus* **54A** 221–244.

Bradley R S *et al.* 2003 in *Paleoclimate, Global Change and the Future*, ed Alverson K D *et al.* [Springer, Berlin] 105–141.

Crucifix M *et al.* 2006 *Space Sci. Rev.* **125** 213–226.

Huybers P 2009 *Science* **325** 1085–1086.

IPCC 2007 *Climate Change 2007: Synthesis Report*. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [IPCC, Geneva, Switzerland] 104 pp; available as: `http://www.ipcc.ch/publications_and_data/ar4/syr/en/main.html`

Jansen E *et al.* 2007 in *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, ed Solomon S *et al.* [Cambridge University Press, Cambridge and New York].

Joussaume S and Braconnot P 1997 *J. Geophys. Res.* **102** 1943–1956.

Kaufman D S *et al.* 2009 *Science* **325** 1236–1239.

Kopp G and Lean J L 2011 *Geophys. Res. Lett.* **38** L01706.

Liu J *et al.* 2007 *Geophys. Res. Lett.* **34** L14702.

Parkinson C L and Cavalieri D J 2012 *The Cryosphere* **6** 871–880.

Pike J *et al.* 2013 *Nature Geoscience* **DOI 10.1038/NGEO1703** 1–4.

Raymo M E and Huybers P 2008 *Nature* **451** 284–285.

Sagarin R 2001 *Nature* **414** 600.

Schiermeier Q 2012 *Nature* **489** 185–186.

Shepherd A *et al.* 2010 *Geophys. Res. Lett.* **37** L13503.

Steel D 2000 *Marking Time* [Wiley, New York].

Tett S F B *et al.* 2007 *Climate Dynamics* **28** 3–34.

Wu Z *et al.* 2011 *Climate Dynamics* **37** 759–773.