On the role of natural multidecadal oscillations on global warming and its hiatus

Mayukha Pal
ABB Ability Innovation Center Hyderabad https://orcid.org/0000-0001-6037-1338
Prasanta K Panigrahi (pprasanta@iiserkol.ac.in)
Department of Physical Sciences, Indian Institute of Science Education and Research Kolkata, Mohanpur 741246, India.

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On the role of natural multidecadal oscillations on global warming and its hiatus

Mayukha Pal[1], **Siddharth Patwardhan**[2,3], **Sudhashu Pandey**[4], **and Prasanta K. Panigrahi**[5,*]

[1]ABB Ability Innovation Center, Asea Brown Boveri Company, Hyderabad 500084, India.
[2]Department of Mathematics and Statistics, Indian Institute of Science Education and Research Kolkata, Mohanpur 741246, India.
[3]Center for Complex Networks and Systems Research, Luddy School of Informatics Computing and Engineering, Indiana University, Bloomington, Indiana 47408, USA.
[4]SRON Netherlands Institute for Space Research, Sorbonnelaan 2, 3584 CA Utrecht, Netherlands.
[5]Department of Physical Sciences, Indian Institute of Science Education and Research Kolkata, Mohanpur 741246, India.
[*]pprasanta@iiserkol.ac.in

ABSTRACT

In this study, we investigate the role of the multidecadal oscillation patterns in the global temperature in the global warming hiatus. We analyse the global instrumental temperature records and multiple tree-ring temperature reconstruction records using wavelet transforms and register the presence of a multidecadal cycle of approximately 55-75 years. The hiatus and post-hiatus rise in temperature arises from the declining phase of the multidecadal oscillation which temporally compensates the rising phase. The unusual rise in the temperature after the hiatus is possibly explained by the positive uprising phase of this natural cycle. The origin of the global warming debate has been partly ascribed to faulty calculations or biased judgments. However, in these studies, little emphasis has been given to the possible presence of multidecadal oscillation patterns in the global temperature, which may lead to such an effect. Our result demonstrates that, phase of this cycle has accidentally played an important role in fuelling the global warming debate. Therefore, while assessing any future climate changes, such possibilities should be accounted.

Introduction

The dynamics of climate evolution is immensely complex, with nonlinear[1–3] interdependent contributions from anthropogenic and natural sources. Planetary scale climate evolution such as inter-decadal[4] and 5kyr[5] cycles, long-term regional variations such the Atlantic Multi-decadal Oscillation (AMO)[6–9], multi-decadal Pacific climate variability[10,11], and natural forcings induced by solar and volcanic activity[12] play a major role in modulating the Earth's climate.The anthropogenic contributions to climate change through greenhouse warming[13–16], ocean acidification[17], and regional radiative forcing[15,18] have been extensively studied and documented. Multi-decadal oscillations, for example, have been shown to have a positive correlation with the global warming[12,19] at different time-scales[20,21]. While the role of AMO in the northern hemispheric climatic variability is now undisputed, a significant factor, i.e., the role of zonal and regional multi-decadal variability in the global temperature dynamics is not yet fully understood[22]. For example, recently, the role of Arctic warming amplification in the global temperature change[23] and a weakening Atlantic Ocean Meridional Circulation[24,25], have been recognised to influence surface heat flux[26], and drought frequencies in the United States[27].

Based on the HadCRUT3 dataset, it was argued in the media that global warming had stopped after 1995[28]. It was observed that the increase in the global mean surface temperature (GMST) after 1998 was not as significant as expected from greenhouse gas production how ever it was reported recently 2016 was warmest year[29]. These deviations in the predictions made by numerous climate models continued till 2012. This period has been referred to as 'global warming hiatus' in the climate science literature. After 2013, numerous studies have investigated the apparent slowdown in global warming[30]. Proposed reasons for the hiatus include increased tropospheric and stratospheric aerosol loading[31,32], natural variability[33–35], and transient climate response[36]. Medhaug et al. extensively explore various climate models proposed to explain the hiatus period[37]. Yao et al. point out the presence of a quasi-60-year multidecadal oscillation related to the Pacific multidecadal and Atlantic multidecadal oscillation may have had a significant impact on the emergence of the hiatus[33]. In this paper, we register the presence of a multi-decadal cycle of approximately 55-75 years in the global instrumental temperature records and show that the cooling phase of the cycle coincides with the hiatus period. Moreover, we register the same periodicity in 10 different paleo-constructed tree-ring temperature reconstruction data encompassing 2000 years with a confidence level of 99%, solidifying the existence of the cycle and its effect on the hiatus.

IPCC reports[38,39] have been the topics of constant debate amongst scientists, with questions being raised about the legitimacy of these assessments[40]. Many claimed that the impact of global warming has been underestimated, as in the case of Arctic sea ice extent shrinkage[41], whereas there have been considerable skepticism about the methodology being employed, with some even accusing IPCC for creating the global warming havoc[42]. Berkeley Earth Surface Temperature project (http://berkeleyearth.org/) have documented, by the analysis of data from over 37,600 global stations, that approximately a third of earth has cooled, with rest of the two-third being warmed in the last 70 years. They conclude that the global temperature have risen by approximately 1^o C since mid 1950s. However, human impact on the climate change is still attracting tremendous debate as the cause of this warming remains elusive. IPCC (2001) report was particularly subjected to criticism in this regard, for overestimating the human impact, with arguments that the global rise in temperature may be solely natural[43]. Although the IPCC (2007) report made it clear that there is dangerous human involvement in the present global warming, the reason for disbelief persisted due to lack of information and improper assessment of data. The recent IPCC reports have broadly corroborated the above picture.

Natural Oscillations

In addition to the possibility of warming due to increased concentration of greenhouse gases and aerosol concentration during the last century, there is evidence that natural forcing has played an important role in climate variations over the past century[44]. The simultaneous increase in solar irradiance in the late 20th century warming is one of the main arguments of the critics of the global warming concern. However, it was shown that the increase in solar forcing cannot account for more than 50% of the global temperature rise[45]. The unforced 'natural variability' of the climate system may also be quite important on multidecadal and centennial timescales[46,47]. In such cases, a careful analysis of the temporal and spatial patterns of global temperature over the past two centuries is paramount to assess possible anthropogenic impact on post-industrial climate.

Numerous studies document patterns in natural phenomena affecting climate, many of these were identified in the solar irradiance data in the form of nearly sinusoidal cycles[48,49]. Modeling of ice core records and other proxies have also unveiled natural oscillations. Three Milankovitch cycles of 20, 40, 100 ky, caused by earth's axial precession, axial tilt (obliquity) and orbital eccentricity, respectively, have affected the climate on a much longer timescale in the past causing glacial-interglacial cycles. Volcanic eruptions and meteorite impacts have also played a major role, with absence of any apparent periodicity. The understanding of these phenomena is prerequisite for assessing the human impact on nature and predicting the future climatic condition of the earth.

Although numerous studies have documented cyclic behavior in paleoclimate data[48,50], they have not concentrated on multidecadal (55-75 years) oscillations in detail. Furthermore, little attention has been given to identify the impact of this cycle in present global warming, although it can be conclusively established by using contemporary instrumental temperature record[51]. Some studies have documented these oscillations in North Atlantic and other parts of Northern Hemisphere[44,51], but have failed to take in to account their global impact on warming. For example, analysis of tree-ring data, for assessment of past El Niño/Southern Oscillation (ENSO), from New Zealand had shown such periodicity[52]. Li et al.[53] found a 50 to 90 years quasi-regular modulation of ENSO using North American Drought Atlas, a database of drought reconstructions based on tree-ring and other proxy records.

In paleoclimate studies, tree-ring data have been widely used for temperature reconstruction and are believed to be the most reliable source for quantitative large-scale temperature reconstruction. Recently, high resolution tree ring and low resolution ocean and lake deposit data have been combined through the multi-resolution capability of the wavelets[54], for reconstructing millennial-scale climate variability of the Northern Hemisphere. Analyses of such data sets provide us with the opportunity of understanding the past temperature variation with good accuracy, small multidecadal oscillation can also be derived from such datasets. To test the presence of multidecadal oscillation, we have used modern instrumental data, zonal annual means of combined land-surface air and sea-surface water temperature anomalies data called land-ocean temperature index (LOTI, deviations from the corresponding 1951-1980 means) is taken from Goddard Institute for Space Studies-Surface Temperature Analysis Project. Analysis of Zonal LOTI (from 1880 to 2010) have been done for Northern and Southern Hemispheres for comparison. To ascertain the presence of this oscillation in past (before 1880) we have used this tree-ring temperature reconstruction data. We have done spectral analysis of these temperature reconstructions to further ensure the presence of this oscillation (see supplementary material). The data from the last decade (2010-Present) has been left for the verification of the inferences made. We find that, the qualitative predictions of temperature data that are made here conform with the data from the last decade.

Results

55-75 years oscillation

The LOTI data sets were first subjected to Fourier transform (Figure 1) for appraisal of underlying oscillations. It converts a time series from the time domain to frequency domain for extracting periodic variations. However, it fails to establish if a particular oscillation is stationary or estimate variation of oscillation in time domain. In the frequency domain, one observes a sharp peak in the range $0.0133 - 0.018\ \mathrm{yr}^{-1}$ which suggests the presence of a 55-75 year oscillation for LOTI data for Northern Hemisphere, Southern Hemisphere, and global LOTI. The power of this oscillation is larger for the Northern Hemisphere in comparison to the Southern Hemisphere, which is indicative that this oscillation may have been caused by Atlantic multidecadal oscillations (AMO)[44,51]. To ascertain whether this oscillation was present in the past we have analyzed multiple temperature reconstructions data (figure 6 in supplementary material).

In the past decade, wavelet transform have emerged as a useful tool for analyzing time series data in climate studies[54]. The advantage which wavelets provide over the traditional Fourier transform is that it is a transformation in both time and space domains, hence, making possible the appraisal of non-stationary oscillations. The wavelet spectrogram of instrumental LOTI reveals that this cycle is present on a global scale (Figure 2a). Although, previous studies have reported a Gleissberg cycle of period of approximately 88 years[55], we have found an oscillation with a period of approximately 55-75 years. It is notable that this oscillation is not prominent in sunspot data, so it cannot be confused with Gleissberg cycle, which is mostly an amplitude modulation of 11-year sunspot cycle[55]. There have been suggestions that this oscillation originates in the Atlantic region[51], but it is found that they are very dominant in whole of Northern Hemisphere (Figure 1b). In Southern Hemisphere, its strength decreases substantially, although it still remains as one of the most dominant oscillation here (Figure 2b), as opposed to the Northern Hemsiphere (Figure 2c). A 4,000-year larch tree ring width chronology and summer temperature reconstruction derived from sub-fossil wood in the Yamal peninsula of western Siberia was produced by Hantemirov et al.[56]. Wavelet spectrogram of this temperature reconstruction data shows the presence of 55-75 years oscillation for the last four thousand years (Figure 2d). It is apparent that this variation is non-stationary in nature and has modulation in its power due to modulation from a higher cycle. This is similar to the observational studies that have shown that the amplitude of El Niño-Southern Oscillation (ENSO) has varied substantially between different multidecadal periods during the past century[57], clearly indicating that the ENSO is also amplitude modulated by multidecadal oscillation.

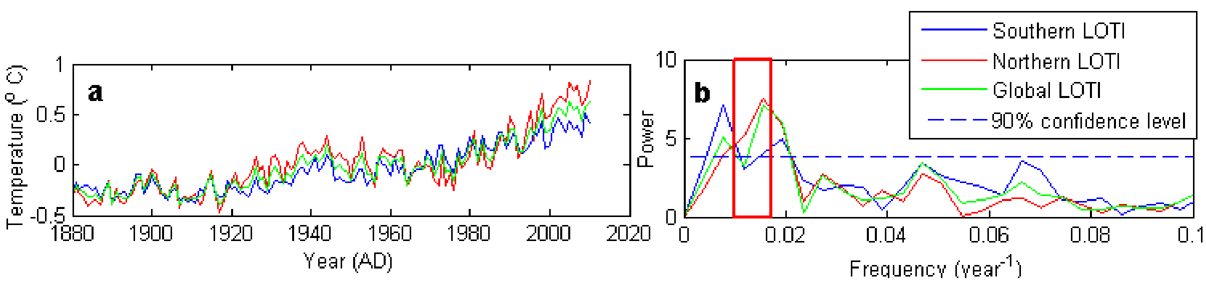

Figure 1. The Fourier spectrogram of the LOTI a, The LOTI for Northern Hemisphere (red), Southern Hemisphere (blue) and Global zones (green). b, The corresponding Fourier spectrogram of the LOTI. The dashed blue line is 90% confidence level on white noise spectrum, and the red rectangle represents the range corresponding to cycles with a period of 55-75 years.

Although, the dominance of 55-75 year oscillation in Northern Hemisphere is more than Southern Hemisphere, its role in affecting climate on a global scale cannot be negated. This is evident form wavelet spectrogram of global LOTI (Figure 2a), where this oscillation is omnipresent. Difference in the properties of the two hemispheres has widely been recorded by many authors. Easterling et al.[58] worked on the global temperature trends and found that, the atmospheric aerosol loading in the Southern Hemisphere is much less than the Northern Hemisphere, suggesting that there are likely a number of factors, such as increase in cloudiness, contributing to the decrease in diurnal temperature range of the Southern Hemisphere. Hence, it can be speculated that the reason for these differences are the tilt angle of earth and the variation of landmass between the two hemispheres.

Mechanism-Atlantic Multidecadal Oscillation

Schlesinger et al.[44] used singular spectrum analysis of the surface temperature records to show that the a 65–70-year oscillation is present in the North Atlantic Ocean and its bounding Northern Hemisphere continents. Later this oscillation was named Atlantic Multidecadal Oscillation[59]. The global impact of AMO does appear as a plausible explanation for these variations, however, whether they are the only cause or not, remains an open research question. In[46], a simulation with a global atmosphere-ocean general circulation model was performed and an oscillation of sea surface temperature (SST) and thermohaline circulation

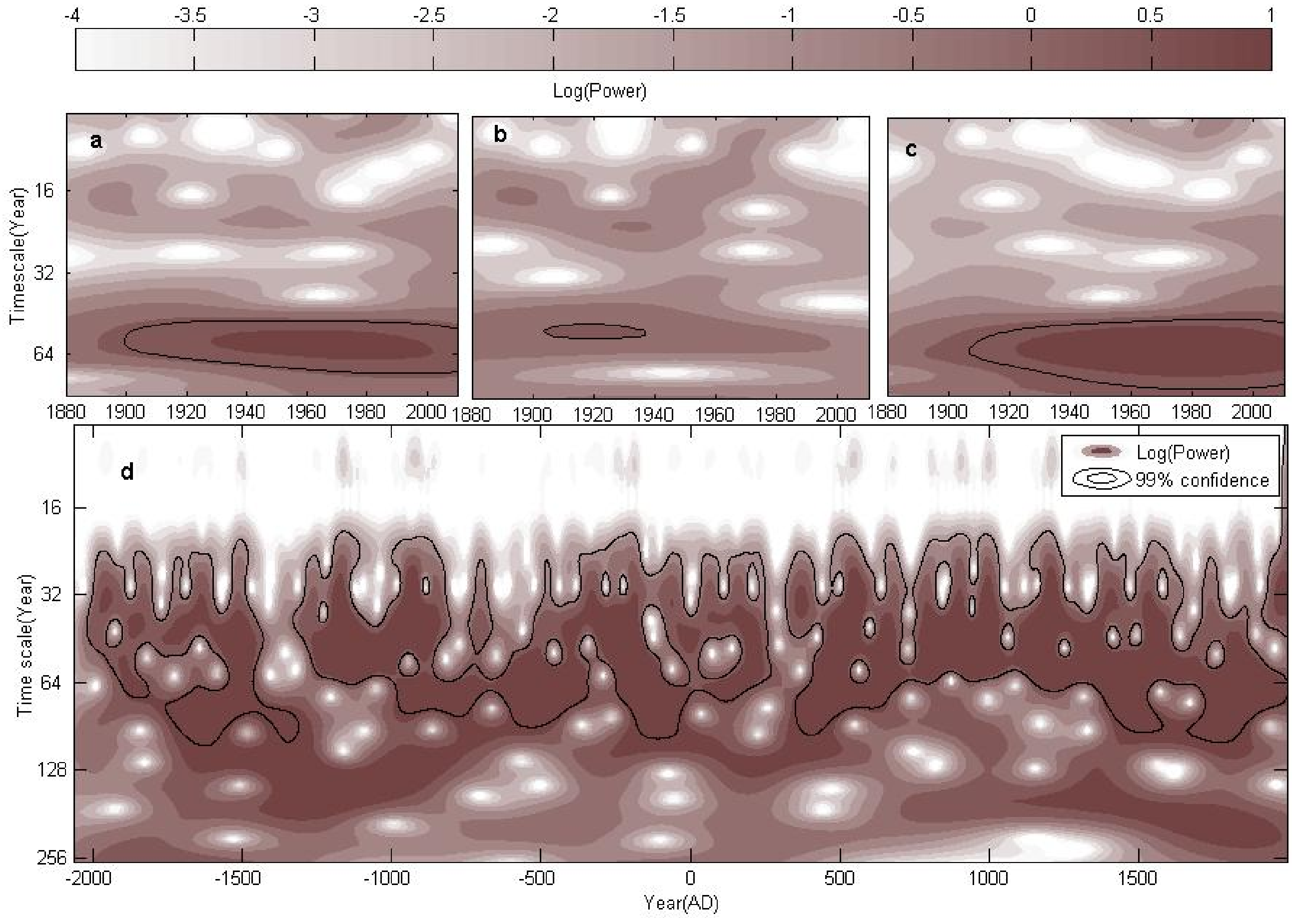

Figure 2. Wavelet spectrogram of the Land-Ocean Temperature Index and Temperature reconstruction data. a, b, c, and d show the Spectrogram of Global, Southern Hemisphere, Northern Hemisphere LOTI and temperature reconstruction, respectively. The black line represents 99% confidence level.

in North Atlantic having a similar timescale was obtained. Over the period 1856 – 1990 a 65–80 year cycle (0.4^o C range) was seen, with warm phases at roughly 1860–1880 and 1930–1960 and cool phases during 1905–1925 and 1970–1990. According to[60], variations in the thermohaline circulation are reflected as uniform sea surface temperature anomalies in the North Atlantic. These anomalies are associated with a hemispheric wavenumber-1 sea level pressure (SLP) structure in the atmosphere that is amplified by the atmosphere–ocean interactions in the North Pacific. The SLP pattern and its wind field affects the sea-ice export through Fram Strait, the freshwater balance in the northern North Atlantic. As a result, it also affects the strength of the large-scale ocean circulation. It generates sea surface temperature anomalies with compensating signs in the North Atlantic and establishes a negative feedback. Henk et al.[61] proposed a mechanism which involves the analysis of solutions of a hierarchy of multiple models. In[61] the lowest member of the model hierarchy (an ocean-only model for flow in an idealized basin) showed variability in a multidecadal oscillatory mode, which is able to destabilize the mean thermohaline circulation. In the highest member of their model hierarchy, multidecadal oscillation is found as a dominant statistical mode of variability. These results have shed some light on the matter along with our analysis result as depicted in Fig 4 and 5.

Discussion

The phase relationship of this oscillation in LOTI data (Figure 3) explains the early 20th century cooling and mid-century warming. It is evident that this oscillation has played a key role in increasing the global temperature from 1970 AD to 2000 AD. This oscillation, along with increased solar activity has obscured the anthropogenic warming in the late 20th century, giving rise to greenhouse debate[38], after subsequent IPCC reports of 1995 & 2001. The anthropogenic factor in warming of earth cannot be neglected, but we conclude that it was over estimated from 1960 AD to 2000 AD, as it was also caused by increased solar irradiance and positive phase of this oscillation. After 2000 AD, this oscillation is having a cooling effect on global temperature,

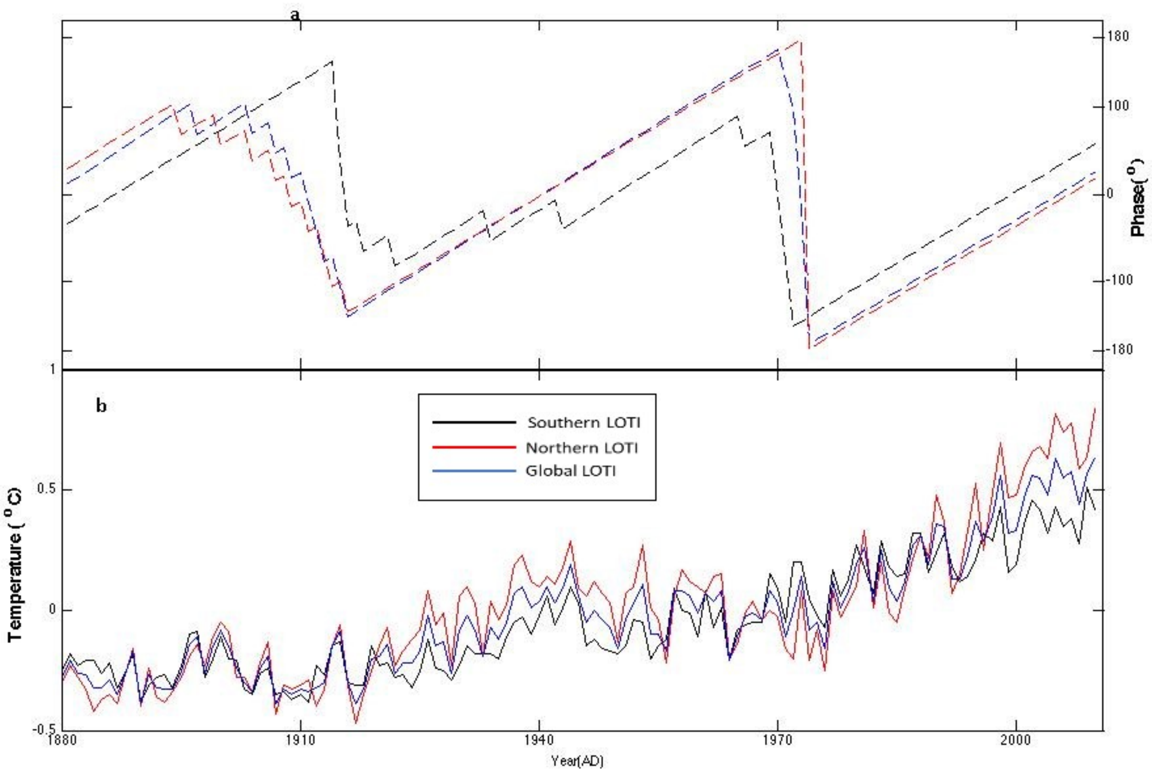

Figure 3. 55-75 year oscillation's phase. a, The figure shows the phase relationship of the multi-decadal oscillation which are extracted from Wavelet spectrogram given in figures 2.a, b, c. It can be observed that this oscillation is responsible for early 20th century cooling and mid-20th century warming. It also played a key role in confounding the global warming in 1970 AD to 2000 AD, where it was in its positive phase along with increase in solar activity[45] and global temperature. b, Plot of the corresponding LOTI for Northern Hemisphere, Southern Hemisphere and whole earth.

which combined with the fact that global temperature is still rising settles the debate in favor of the believers of "anthropogenic influence." Moreover, the predicted results qualitatively conform with the data from the last decade.

The future implications of this oscillation are also interesting and should be included in any simulation or forecasting study. Keeping in mind the nonlinear behavior of the time series, Deep learning algorithms should be well suited for its modeling. From around 2030-2055 AD the oscillation will be again in a positive phase and the global temperature will increase with an alarming rate than otherwise estimated. Therefore, it is important that we take into account any such variations before forecasting the future climate changes.

Our continuous wavelet analysis used the complex Morlet wavelet to plot the spectrogram, as depicted in Fig 2 a, b and c for Global, Southern and Northern LOTI. We further used the phase angle from this analysis and plotted it in Fig 3a to show the phase relation among each other along the time scale. Fig 3b is the actual plot of all LOTI data.

With the use of complex Morlet wavelets in our analysis, the coherence between the wavelet coefficients among the two analysed time series has been made evident. More specifically, in Fig 5 we have used AMO and Global LOTI to perform both the cross-wavelet transforms, and coherence analysis, for establishing the local phase locking and correlation strengths along the time-frequency domain. In the coherence plot, we observe more arrows pointing rightward or right downwards indicating both AMO and Global LOTI are either in-phase or one drives the other.

The wavelet 3D scalogram analysis shows clear visible multidecadal cycles of 55-75 years as depicted in the Fig 4. From the performed cross-wavelet and wavelet coherence analysis between AMO and Global LOTI as shown in Fig 5 for correlation, in-phase and dependency analysis shared the local phase locking and correlation strengths along the time-frequency domain.

From the coherence plot, we observe AMO and Global LOTI are either in-phase or one drives the other indicated from the fact that there are more arrows pointing rightward or right downwards in Fig 5. The observed periodicity shows the natural cooling and heating duration of 55-75 years. The global warming hiatus is plausibly a natural product of the interplay between a secular warming tendency due in a large part to the build-up of anthropogenic greenhouse gas concentrations, in particular CO2 concentration, and internally generated cooling by a cool phase of a quasi-60-year oscillatory variability, that is closely associated with the Atlantic multi-decadal oscillation[33].

Methods

Analyses of datasets were performed on Mathwork Matlab Platform, for assessment of multidecadal oscillations. The mean of all the temperature series are set to zero for analyzing periodic variations. As we are interested only in periodic variations, detrending of the time series is done by removal of mean line growth function. As the paleoclimate (see Figure 6 in the supplementary material) data are comparatively longer and contained significant noise, denoising from high frequency oscillations is done using Daubechies-4 wavelet at level 4. Fourier transform is applied for preliminary assessment of the oscillation (figure 6 in supplementary material) and Monte Carlo method is used for comparing the Fourier peaks with 99% confidence level in white noise spectrum. To understand the non-stationary nature of periodicities, we applied continuous wavelet transform using Morlet wavelet, as it gives a representation of the data in time-frequency domain. The wavelet spectrogram of these data is shown in Figure 1. A 99% of confidence level is achieved using the approach given in Torrence et al. We extracted the scale between 55 to 75 years and averaged them. The phase relationship of oscillations of these scales along with the actual LOTI data is plotted in Figure 3.

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Author contributions statement

P.K.P. conceived the experiment(s), Si.P. and Su.P. conducted the experiments and analysed the results. M.Pal performed the wavelet analysis. All authors reviewed the manuscript.

Additional information

GISTEMP data provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their Web site at https://www.esrl.noaa.gov/psd/.

Accession codes Analyses of all the data were performed on Mathwork MATLAB Platform.

Competing interests The authors have no interests to disclose.

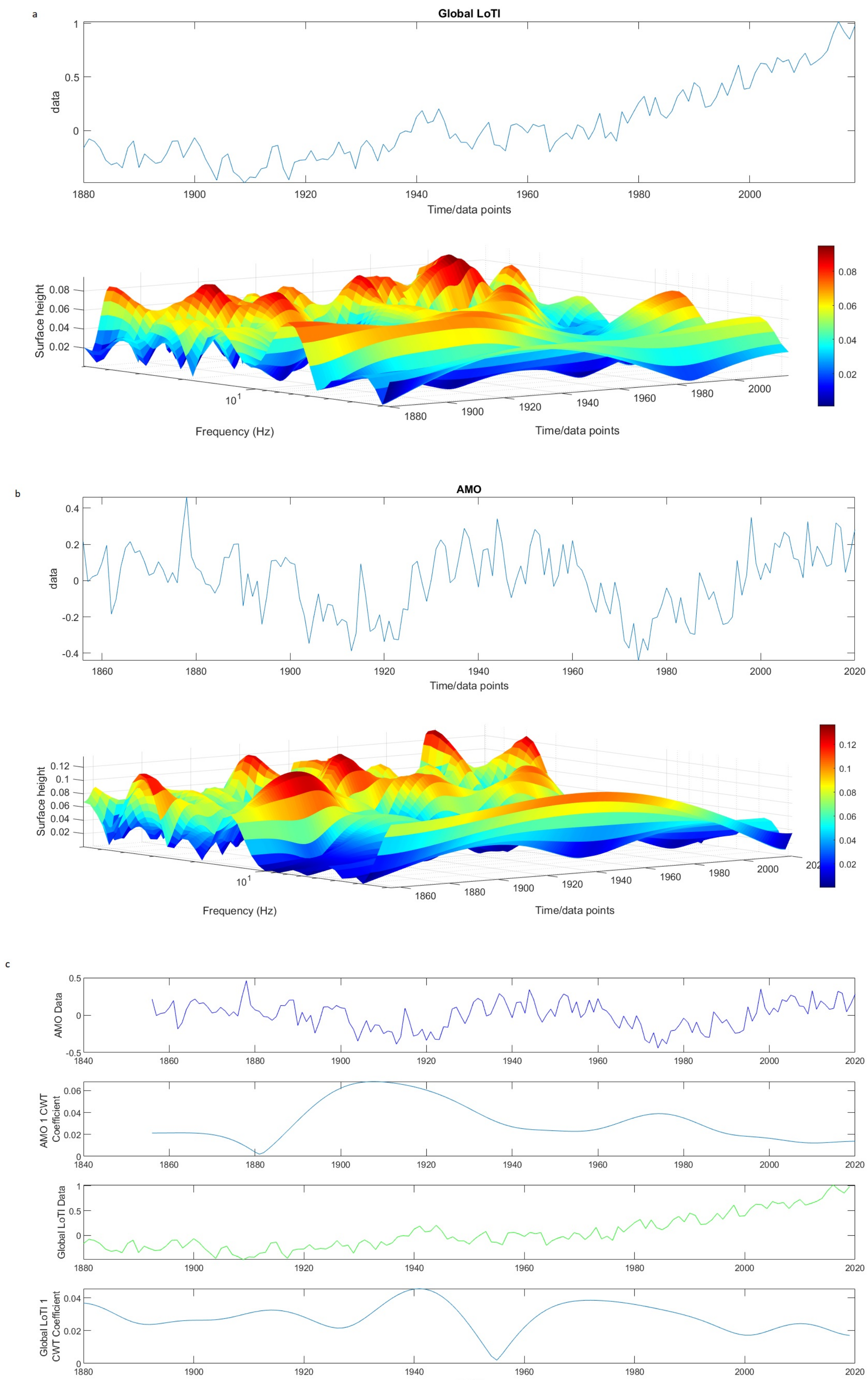
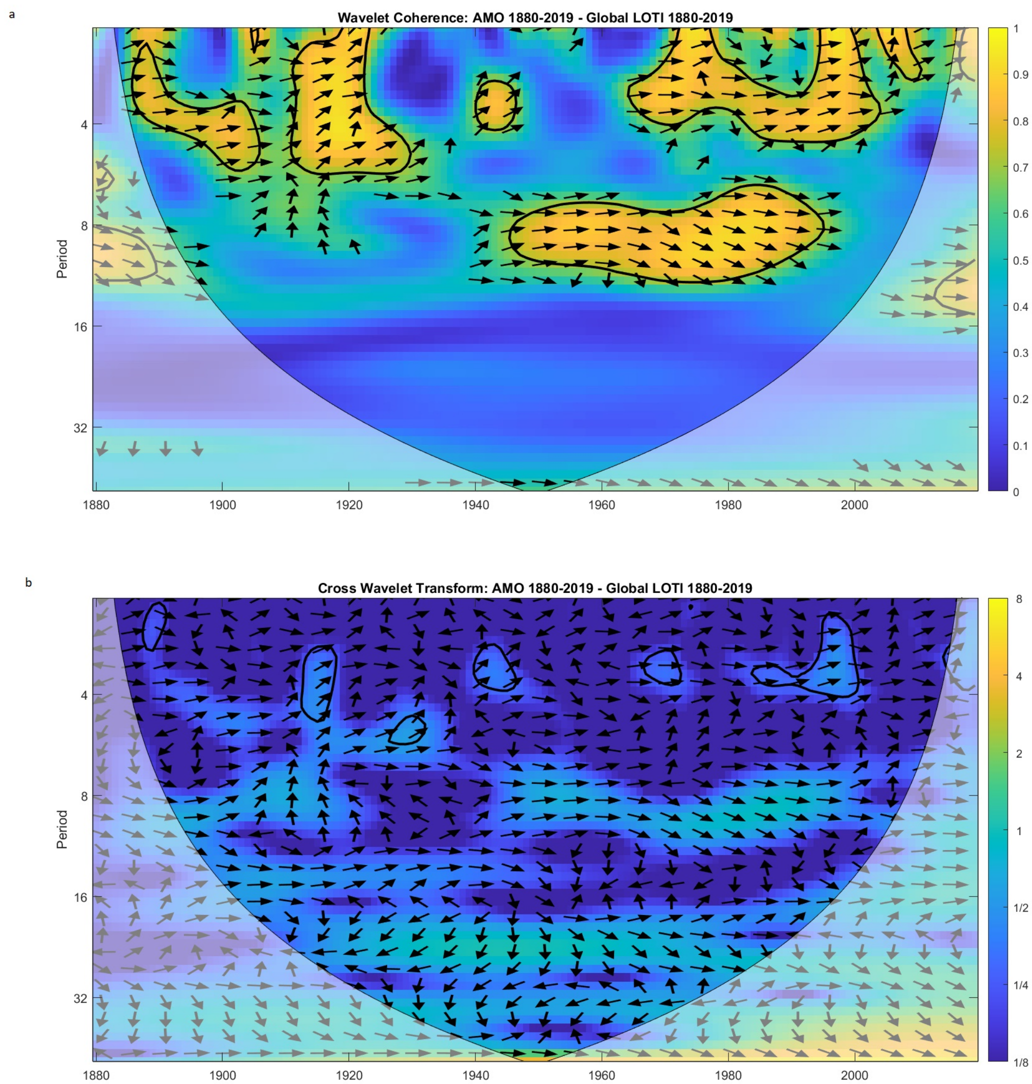


Figure 4. 3D Scalograms. a, The figure shows the Global LOTI data and its 3D Scalogram depicting multi-decadal oscillation from the continuous wavelet analysis using complex Morlet wavelet. b, Plot of the AMO data and its 3D Scalogram. c, Plot of data along with one of the CWT coefficient of both Global LOTI and AMO clearly depicting the oscillation with hiatus.



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Supplementary material

To further test the presence of this oscillation, we have applied Fourier transform on 10 paleo-temperature reconstruction datasets (Figure 6). The peaks above the 90% confidence line show that 55-75 year oscillation is present in these datasets. The dataset was taken from National Oceanic and Atmospheric Administration (NOAA) website (http://www.noaa.gov/). The citations for data used in the figure are as follows:

1. Cook, E.R., et al., 2003, Kathmandu, Nepal Temperature Reconstructions, IGBP PAGES/World Data Center for Paleoclimatology Data Contribution Series #2003-038. NOAA/NGDC Paleoclimatology Program, Boulder CO, USA.

2. MacDonald, G.M., and R.A. Case. 2006. Pacific Decadal Oscillation Reconstruction for the Past Millennium. IGBP PAGES/World Data Center for Paleoclimatology Data Contribution Series # 2006-023. NOAA/NCDC Paleoclimatology Program, Boulder CO, USA.

3. Moberg, A., et al. 2005. 2,000-Year Northern Hemisphere Temperature Reconstruction. IGBP PAGES/World Data Center for Paleoclimatology Data Contribution Series # 2005-019. NOAA/NGDC Paleoclimatology Program, Boulder CO, USA.

4. D'Arrigo, R., et al. 2006. Northern Hemisphere Tree-Ring-Based STD and RCS Temperature Reconstructions. IGBP PAGES/World Data Center for Paleoclimatology Data Contribution Series # 2006-092.NOAA/NCDC Paleoclimatology Program, Boulder CO, USA.

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10. Michael E. Mann, Raymond S. Bradley, and Malcolm K. Hughes, 1998, Global Six Century Temperature Patterns, IGBP PAGES/World Data Center-A for Paleoclimatology Data Contribution Series # 1998-016. NOAA/NGDC Paleoclimatology Program, Boulder CO, USA.

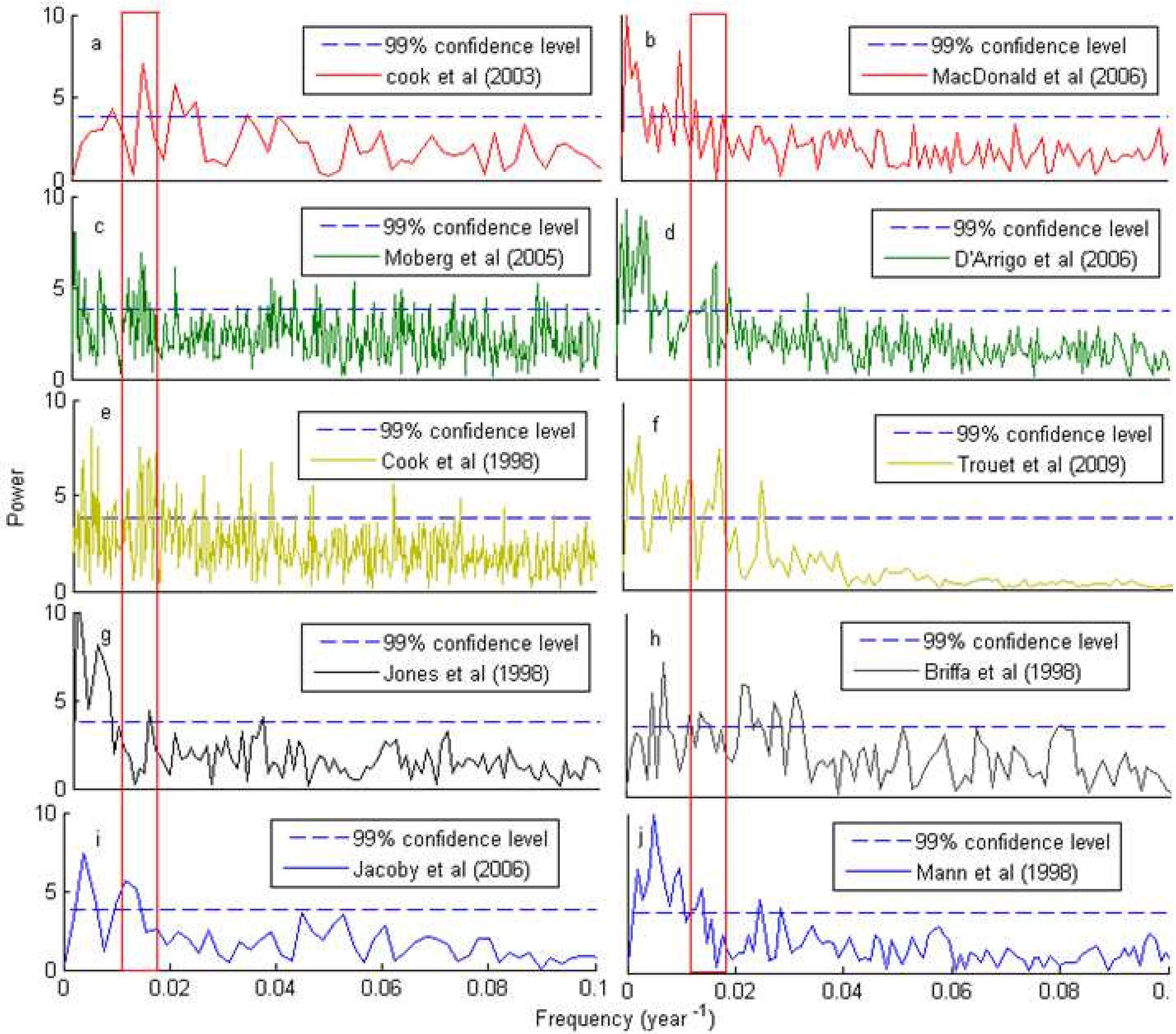


Figure 6. The Fourier scalogram of Temperature reconstruction data form various Scientists. The red box represents the frequency range corresponding to 55-75 years period oscillation. The reconstruction data used are (a) Post-monsoon (October-February) temperature reconstruction for Kathmandu Original Mean.[1] (b) Pacific Decadal Oscillation Reconstruction for the Past Millennium.[1] (c) 2,000-Year Northern Hemisphere Temperature Reconstruction.[3] (d) Northern Hemisphere Tree-Ring-Based STD and RCS Temperature Reconstructions.[4] (e) Tasmania Temperature Reconstruction.[5] (f) Multi-decadal Winter North Atlantic Oscillation Reconstruction.[6] (g) Millennial Temperature Reconstructions (Global).[7] (h) Northern Hemisphere Temperature Reconstructions.[8] (i) Taymir, Siberia Warm Season Temperature Reconstruction.[9] (j) Global Six Century Temperature Patterns.[1]0. Refer to the note below for further details and citation of the data.

Figures

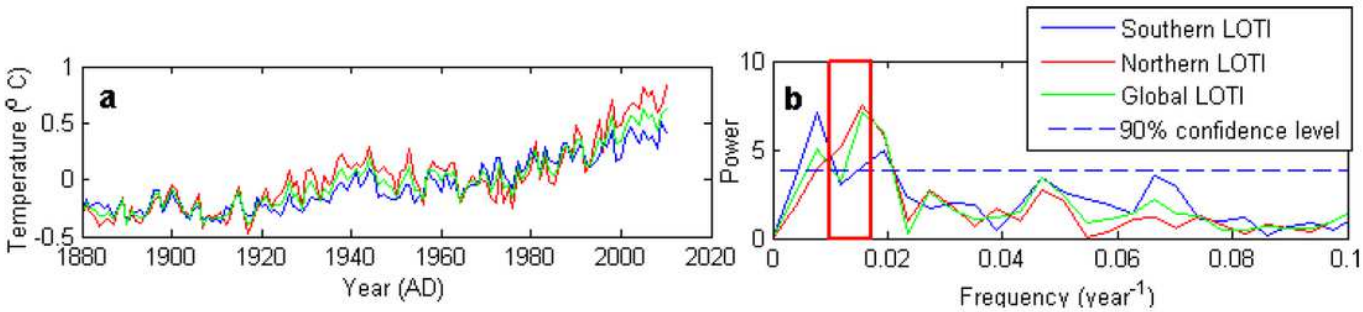


Figure 1

The Fourier spectrogram of the LOTI a, The LOTI for Northern Hemisphere (red), Southern Hemisphere (blue) and Global zones (green). b, The corresponding Fourier spectrogram of the LOTI. The dashed blue line is 90% confidence level on white noise spectrum, and the red rectangle represents the range corresponding to cycles with a period of 55-75 years.

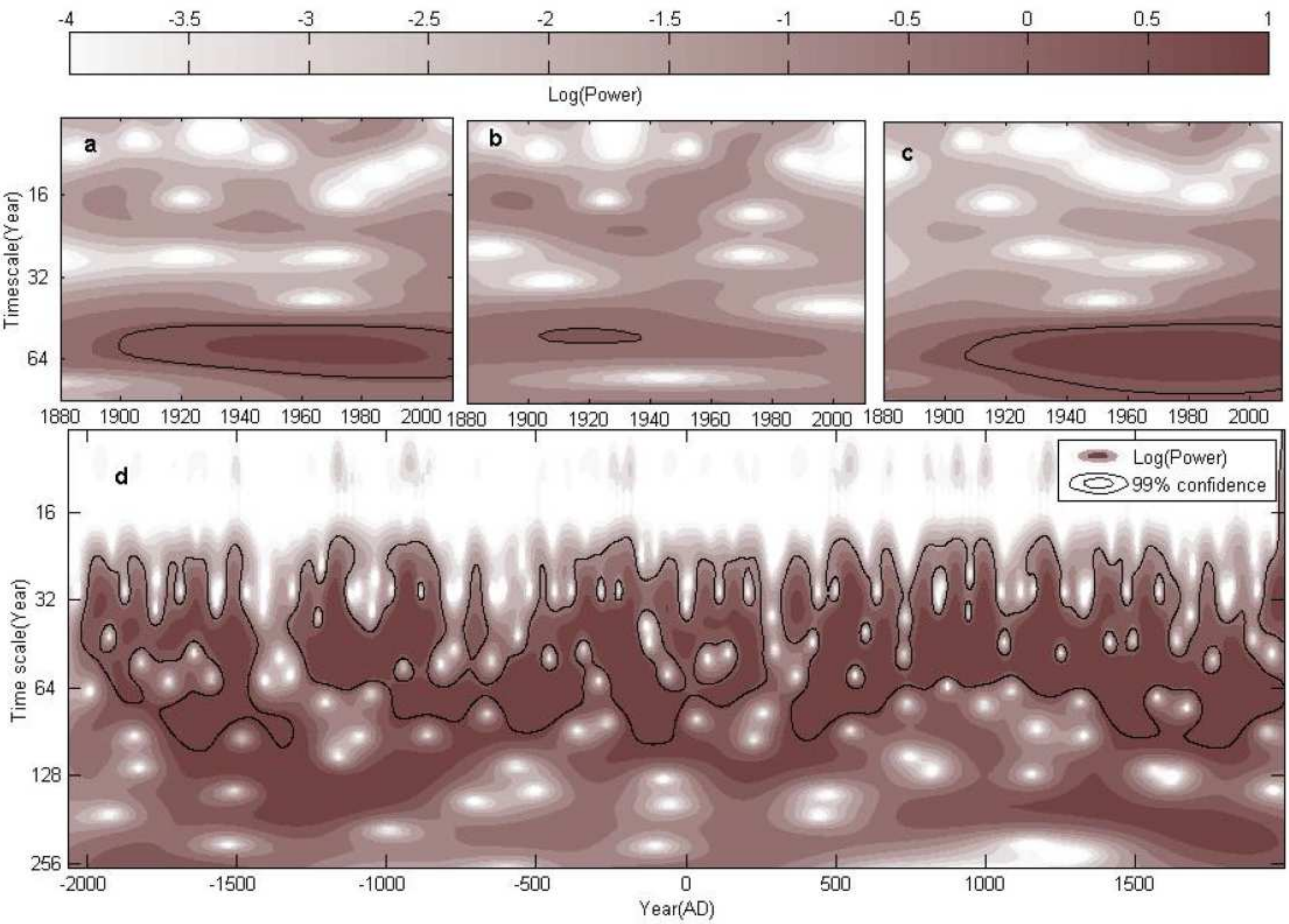


Figure 2

Wavelet spectrogram of the Land-Ocean Temperature Index and Temperature reconstruction data. a, b, c, and d show the Spectrogram of Global, Southern Hemisphere, Northern Hemisphere LOTI and temperature reconstruction, respectively. The black line represents 99% confidence level.

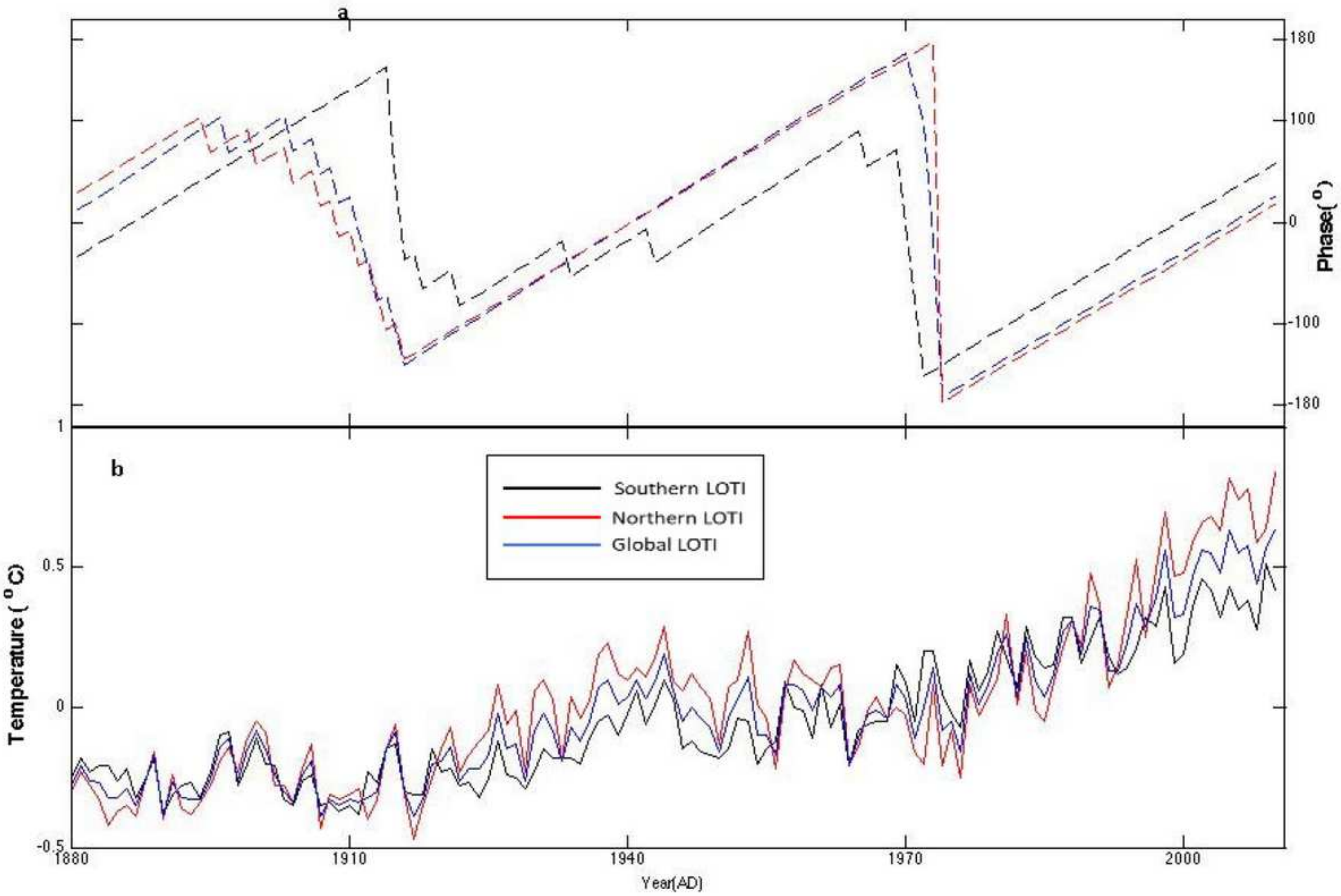
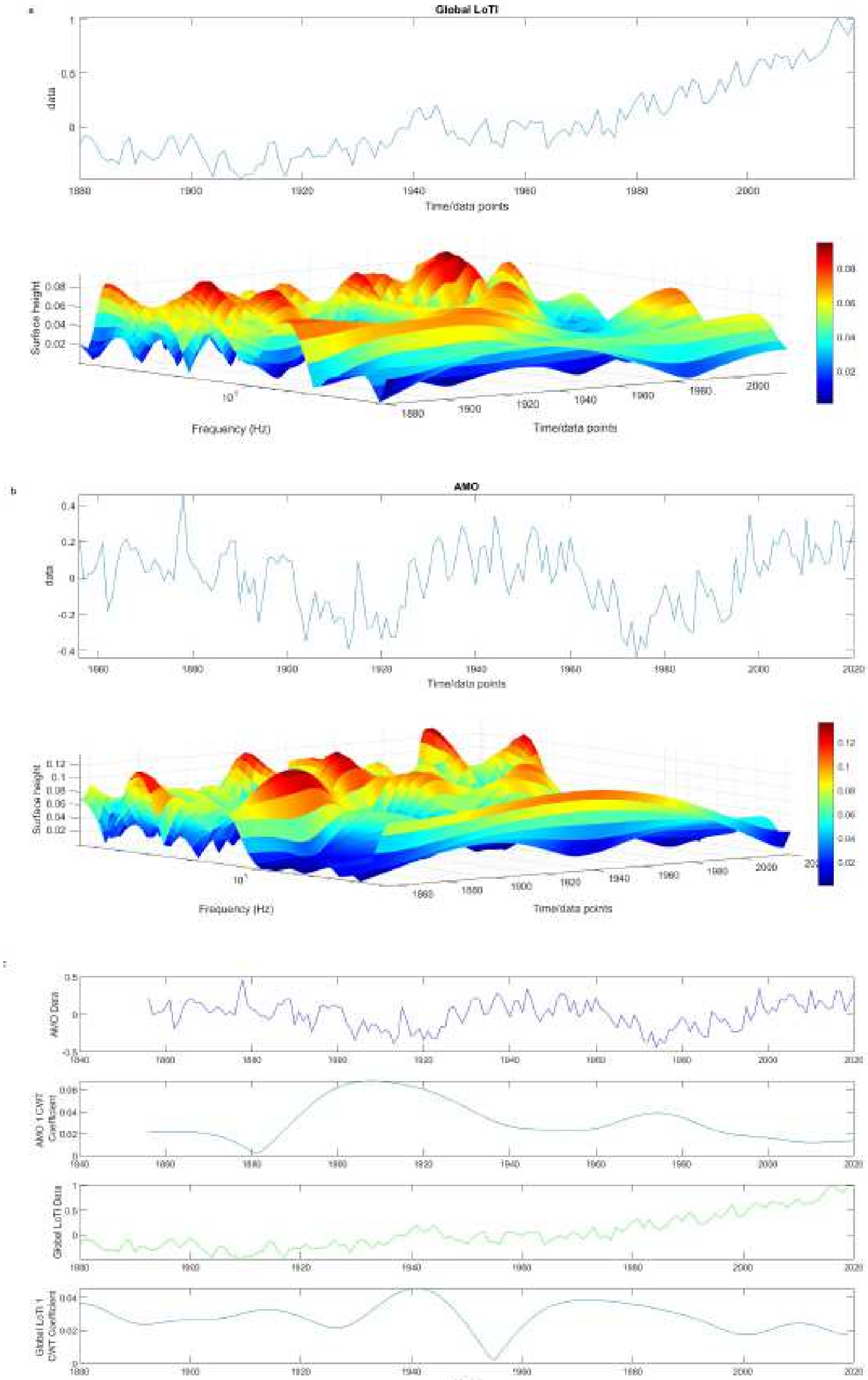


Figure 3

55-75 year oscillation’s phase. a, The figure shows the phase relationship of the multi-decadal oscillation which are extracted from Wavelet spectrogram given in figures 2.a, b, c. It can be observed that this oscillation is responsible for early 20th century cooling and mid-20th century warming. It also played a key role in confounding the global warming in 1970 AD to 2000 AD, where it was in its positive phase along with increase in solar activity45 and global temperature. b, Plot of the corresponding LOTI for Northern Hemisphere, Southern Hemisphere and whole earth.



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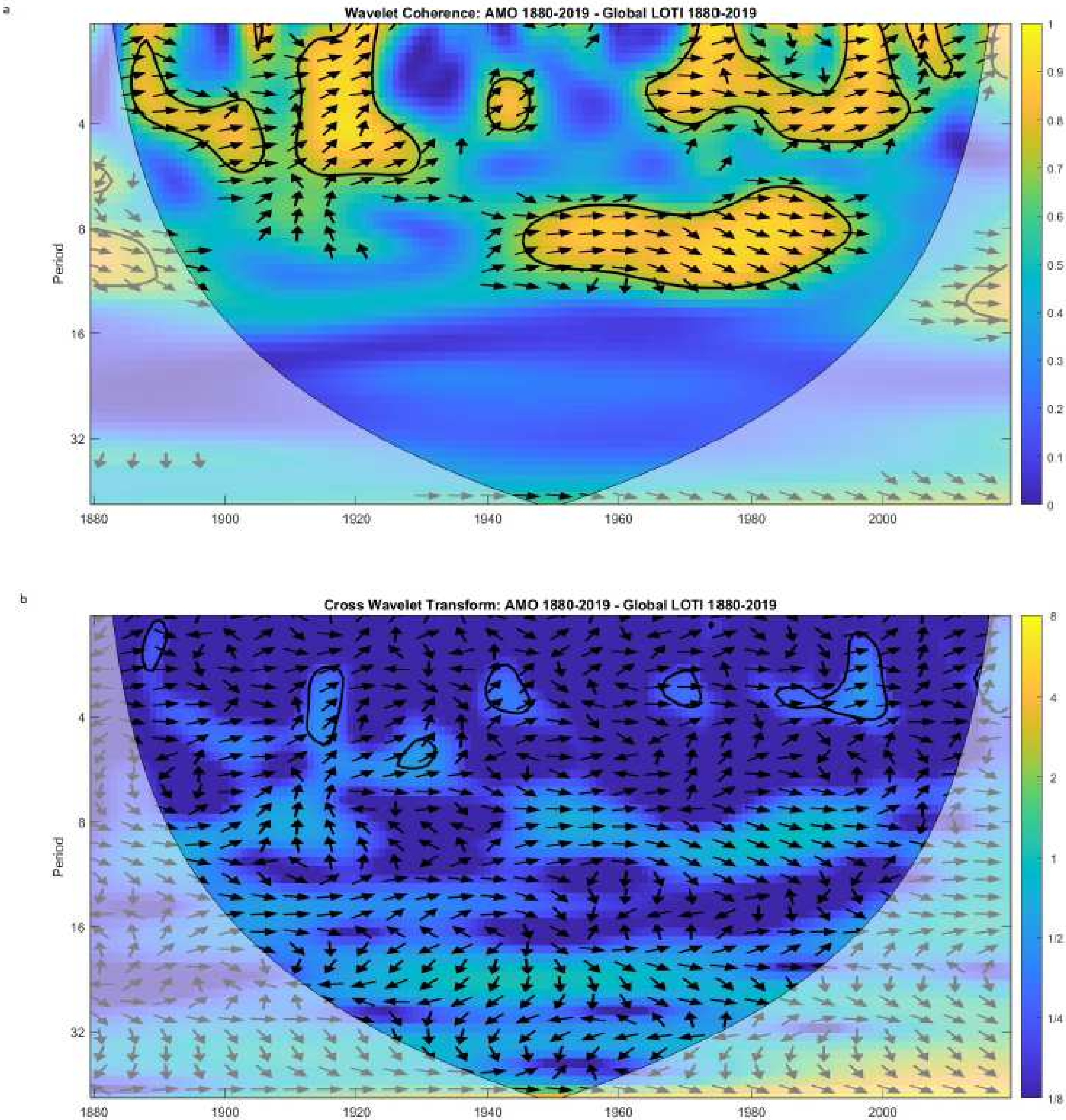

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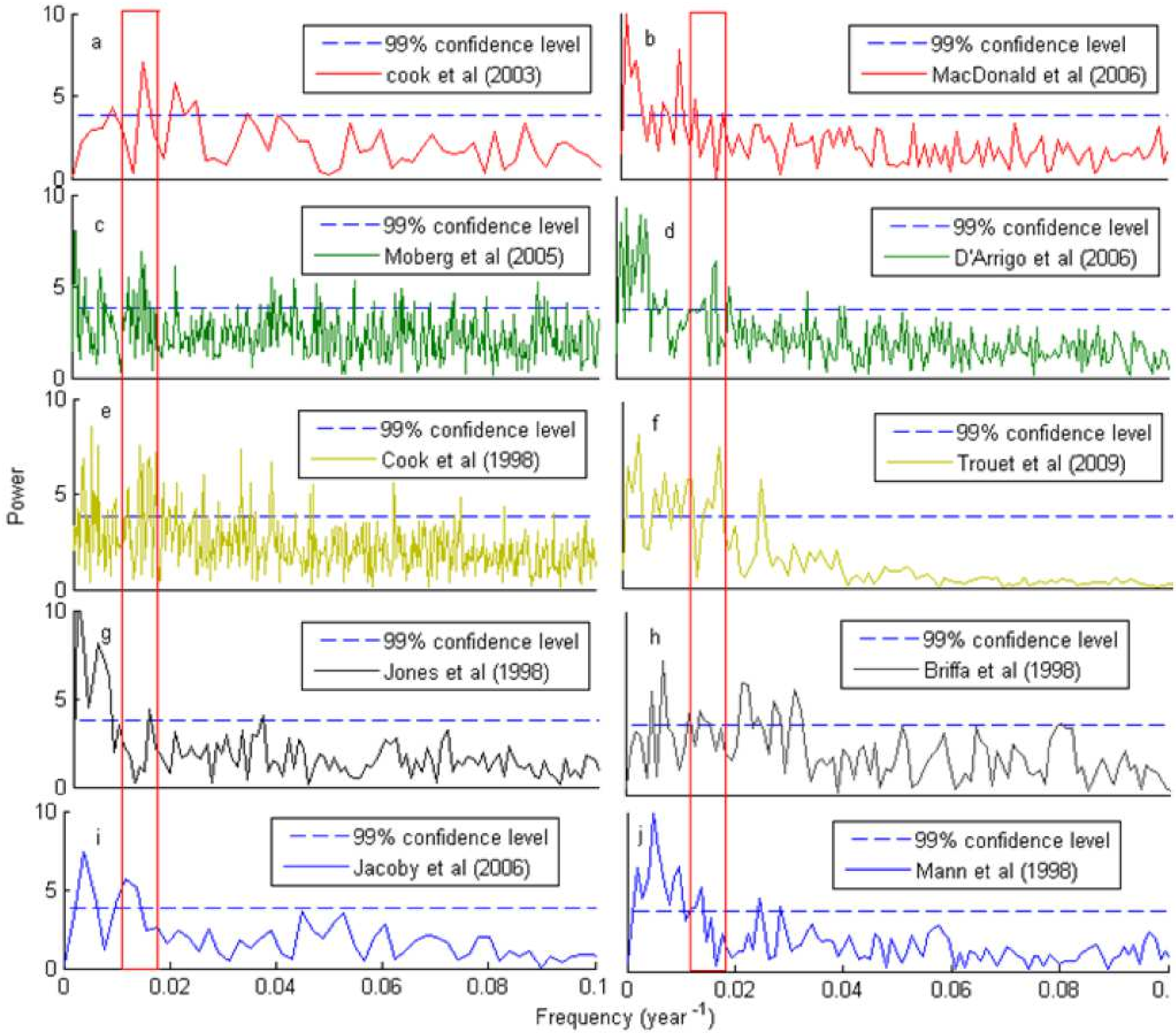

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