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An Analysis of Climate Forcings from the Central England Temperature (CET) Record

Alan D. Smith[1*]

[1]Department of Earth Sciences, University of Durham, Durham, DH1 3LE, UK.

Author's contribution

The sole author designed, analyzed and interpreted and prepared the manuscript.

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ABSTRACT

The Central England Temperature (CET) record is the world's longest instrument-based temperature record and covers the years 1659-present. The temperature variation of 0.8°C between the Maunder Sunspot Minimum in the late 17th Century and the beginning of the Industrial Revolution in the mid-late 18th Century can be explained by fluctuations in solar output (TSI) alone. Thereafter, approximately one third of the temperature increase to the present may be attributed to increases in atmospheric CO_2, with the anthropogenic contribution to Global Warming/Climate Change up to the end of the 20th Century estimated at 0.4 to 0.5°C.

Keywords: Climate change; Central England Temperature record; solar forcing, oceanic oscillation; CO_2.

1. INTRODUCTION

The argument that has generally been presented in climate modelling is that there is clear evidence for greenhouse gas emissions (the anthropogenic global warming, AGW model) dominating warming of the Earth's climate [e.g. 1-3]. However, the argument is controversial because AGW is superimposed on natural climate forcings and distinguishing these is complex because of the number of effects [4]. Natural climate forcings include Earth orbital effects, ocean circulation, solar output, volcanic eruptions, and variations in atmospheric patterns [5]. Nonetheless, with the exception of volcanoes, the natural forcings are long-term cyclical effects whereas AGW should increase progressively. Hence it should be possible to distinguish these mechanisms given suitable climate records. The Central England Temperature (CET) record has particular importance with regard to this issue as it is the world's longest continuous instrument-based temperature record.

**Corresponding author: E-mail: muic2000@yahoo.com;*

The CET record is a compilation of temperatures for the region defined by the triangle central Lancashire-Bristol-London in the UK. The record was originally compiled by Manley [6] but has been updated for recent years by the Met Office [7]. Covering the years 1659-present, the record spans the latter years of the Little Ice Age when climate variation should only result from natural climate forcings, through the beginning of the Industrial Revolution (circa 1760) to modern times when warming has been suggested to result from CO_2 emissions into the atmosphere. Variations in the Sun's output have been proposed as the principal alternative mechanism of climate change [8], and the time period covered by the CET record also coincides with that for which variations in solar output are constrained by direct observation.

2. MODELLING THE CET RECORD

In order to avoid the issue of whether climate warming has slowed during the last decade [9], this study focuses on the temperature variation in the CET record up to the end of the 20th Century. Yearly mean temperatures in the CET record show an increase in temperature of approximately 1.3°C degrees from the end of the 17th Century to the end of the 20st Century/ beginning of 21st Century (Fig. 1, Tables 1, 2). The temperature increase follows a saw-toothed pattern, with episodes of increasing and decreasing temperatures occurring over periods of 2 to 4 decades. Within the 20th Century alone there are two decade-long warming periods and one cooling period. Similar temperature trends are noted elsewhere such as Antarctica (warming ~1915-1945 and 1946-present; cooling ~1946-1970 [8]) and North America (warming 1910-1945, 1974-1998; cooling 1946-1973 labelled *The Cooling* by Ponte [10], Fig. 1). Subtle difference in timing between the warming/cooling phases between the Central England record and the other localities may reflect local climate variation, but the similarity in events between continents suggests the CET record is recording global temperature patterns.

Cooling episodes predominate within the first half of the CET record, whereas warming predominates during the latter half. Cooling trends tend to become less steep over time whereas warming trends become steeper. The temperature increase over the last few centuries does not follow a simple pattern, possibly indicating a short-wavelength pattern superimposed on a cycle whose wavelength is longer than the time interval covered by the CET record (Fig. 1b). The overall progression toward higher temperatures termed Global Warming or Climate Change, appears to be the result of a preponderance of phases of increasing temperature, compared to a predominance of cooling phases within the years of the Little Ice Age.

3. CORRELATION WITH THE AGW MODEL

AGW models often assume a cause-and-effect relationship between atmospheric CO_2 and temperature [e.g. 3], and despite the complexities in the CET record, at first approximation it appears to fit a simple AGW model (Fig. 2). The thermal consequences of increasing CO_2 concentrations have however been quantified in the field of planetary science, where the studies of Lindzen [11] and Charnock et al. [12] can be considered end-member models for the magnitude of heating effects. These models suggest a CO_2 increase of 88 ppm, the difference between the pre-industrial and late 20th Century averages, should produce a temperature rise of 0.26 to 0.58°C, considerably less than the observed rise of 1.32°C in the CET record (Table 2).

Likewise, the ability of the AGW model to explain the magnitude of climate variation has been questioned on account of the apparent mid 20th Century cooling phase because there was no concomitant decrease in CO_2 [4,8]. The same argument applies from the perspective of the CET record, with the need for other climate forcings further illustrated by the observation that the temperature rise from pronounced cooling at the end of the 17th Century to warming at the beginning of the 18th Century, covered a range of 85% of the entire CET record during a time period during which atmospheric CO_2 was near constant (Fig. 2).

4. NATURAL CLIMATE FORCINGS

Volcanoes release ash into the atmosphere which causes cooling by reflection of solar radiation, but volcanic eruptions are random and their effects are short term. Over the last millennium, only the 1815 eruption of Mt. Tambora in Indonesia can be linked with unusually cool temperatures, as in 1816, the "year without summer". Therefore, of the natural forcings, volcanic eruptions are the most readily discounted as a mechanism for producing the temperature variations observed in Fig. 1. Correspondingly, Earth orbital effects have either very short term (day/night and seasons) or long-term influences (eccentricity; ~100,000 year cycle; obliquity; 41,000 year cycle; precession; ~23,000 year cycle). Such effects are a major factor in cycles of glacial and interglacial periods which occur over tens of thousands of years, but they are likewise discounted as having the wrong wavelength to explain the temperature variations in the CET record.

4.1 Ocean Circulation Cycles

Atmospheric and ocean circulation effects are closely linked and can be considered together. The El Niño (higher than average east-central Pacific water temperatures) and La Niña (lower than average east-central Pacific water temperatures) are rapid cycles operating over periods of months. Both are part of a longer pattern of coupled ocean-atmosphere interactions patterns known as the Pacific Decadal Oscillation (PDO) [13]. The PDO has a wavelength of around 60 years, comprising one warm phase (having a high proportion of El Niños) and one cool phase (high proportion of La Niñas). A similar oscillation occurs in the North Atlantic (NAO), but as the Pacific has the greater volume (49% of world's ocean water compared to 11% in the North Atlantic), the NAO follows the PDO, although with a delay of few years.

The 20th Century warming and cooling events in the CET record correlate well with the PDO (Fig. 3). Pre-mid 19th Century PDO reconstructions are constructed from tree-ring and coral data and have lower confidence than the 20th Century reconstructions which are based on instrumental data [14]. Cool phases in the CET record correlating with early PDO cycles can be identified in the CET record from 1730-1760 and 1800-1820, but for much of the early record there is only partial overlap. Nonetheless, as for overall trends in the CET record, cooling cycles dominate the PDO before 1825, whereas warm cycles predominate from the mid 19th Century to the present. The transition corresponds to the end of the Little Ice Age as determined from historical evidence [15]. However, oceanic and atmospheric circulation can only redistribute heat as neither generates it, hence the cause of warming by natural variation must lie elsewhere, with solar output remaining as the final variable to be considered.

4.2 Solar Variation

Solar heating of the Earth's atmosphere is expressed as Total Solar Irradiance (TSI = solar power per unit area), and is calculated from parameters including the amplitude, length and decay rate of sunspot cycles, darkness of sunspots, and the rotation rate of the Sun [16]. Records of sunspot numbers began in 1610 such that detailed estimates of solar variation for the years covered by the CET record can be made without resort to the use of proxy data. Reconstructions of TSI [e.g. 16-18] differ in magnitude (Table 1), but there is agreement in form with 4 peaks and 4 to 6 troughs occurring over the time-scale of the CET record (Fig. 4). These are: a minimum in TSI associated with the Maunder Sunspot Minimum in the latter half of the 17th Century; a peak, possibly bi-modal approaching modern TSI values during the 18th Century; a well-defined trough corresponding with the Dalton Sunspot Minimum between 1800-1820; a poorly defined TSI peak in the mid 19th Century; a reduction in TSI during the late 19th Century; increasing TSI during the early 20th Century; a decrease in TSI from around 1950-1975; and a second phase of TSI increase in the late 20th Century. There is good correspondence with TSI throughout the CET record, with warm events correlating with high TSI and cool phases correlating with plateaus or decreases in TSI (Fig. 4).

The effects of changes in TSI are calculated in Table 2 following the relationship suggested by Hoyt and Schatten [16] that a 1% variation in TSI equates with a 1.67°C variation of temperature. The higher estimates of TSI variation [17,18] can account for the temperature variation prior to the Industrial Revolution (Maunder Minimum to Early 18th Century and Dalton Minimum events; Table 2). However, for temperature increases from the beginning of the Industrial Revolution (Maunder Minimum and Dalton Minimum to end of 20th Century), high TSI models can account for only 63-67% of the temperature increase. This would suggest that one third of Global Warming/Climate Change can be attributed to AGW. A comparable estimate of the Sun being responsible for 65% of climate warming was made by Scafetta [19]. Variations in solar output may also occur over long wavelengths (1300-1500 years [20]), potentially explaining the apparent superimposition of patterns in Fig. 1b.

Table 1. Model parameters

Years	Episode	Average T_{CET} °C	CO_2 ppm	TSI [16] W/m^2	TSI [17] W/m^2	TSI [18] W/m^2
1670-1700	Maunder minimum	8.69	280	<1367.4	1359.25	1352.5
1720-1740	Early 18th C	9.5	280	1371	1365.25	1359
1800-1820	Dalton minimum	8.98	280	1368	1360.75	1356.5
1980-2010	Recent	10.01	368	1372.5	1366	1361.65

Table 2. Calculated temperature increases in °C

Time Interval	CET	$CO_{2\ Lindzen}$	$CO_{2\ Charnock}$	TSI_{Hoyt}	$TSI_{Shapiro}$	$TSI_{Velasco}$
Maunder to Dalton	0.29	0	0	0.06	0.19	0.25
Maunder to early 18thC	0.81	0	0	0.44	0.73	0.8
Dalton to recent	1.03	0.26	0.58	0.55	0.64	0.63
Maunder to recent	1.32	0.26	0.58	0.61	0.83	0.88

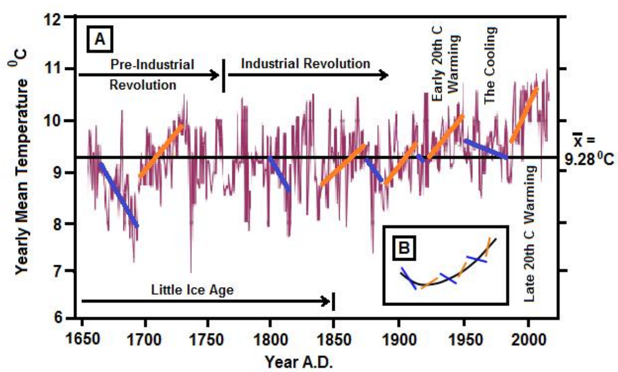

Fig. 1. (a) Yearly temperature variation in the CET record 1659-2016, showing suggested decadal warming and cooling trends in orange and blue, respectively. (b) Schematic illustration of how the decadal trends could be superimposed on a longer-wavelength (several centuries) temperature cycle

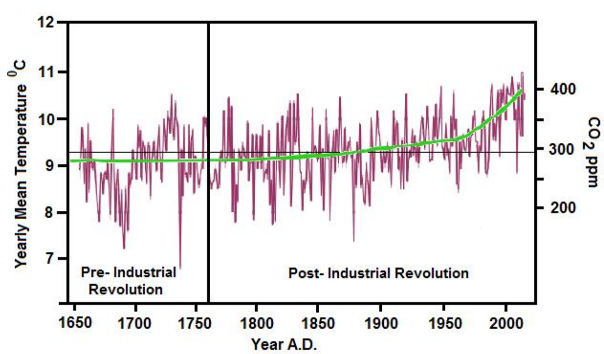

Fig. 2. Temperature variation in the CET record relative to the variation of atmospheric CO_2 (green curve)

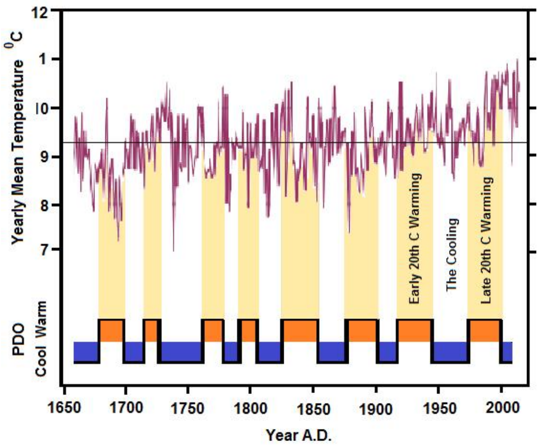

Fig. 3. Comparison of the CET record with a schematic of the Pacific Decadal Oscillation (PDO; [13])

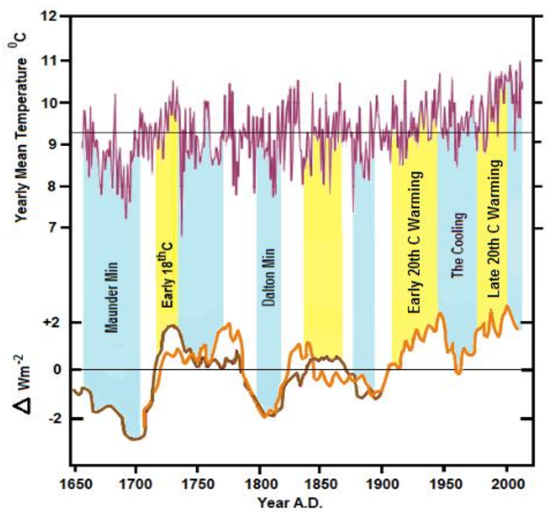

Fig. 4. Comparison of the CET record with Total Solar Irradiance (TSI, expressed as a deviation relative to the 20th Century minimum; orange = Hoyt and Schatten [16], Dark red = Shapiro et al. [17])

5. CONCLUSION

The CET record spans the end of the pre-industrial era to modern times making it of particular relevance to the evaluation of the roles of natural cycles versus anthropogenic causes in climate change. Of the natural climate influences, volcanoes are too random, and Earth orbital effects have too-long a cycle to explain the temperature variation over the time period covered by the record.

Ocean circulation oscillations correlate over part of the CET record, mainly during the 20th Century. But if climate was driven only by ocean circulation effects a monotonous climate cycle would be expected. The transition from predominantly cooling to warming cycles during the mid 19th Century suggests an additional, underlying long-wavelength climate influence. Variations in TSI can explain the magnitude of climate change prior to the Industrial Revolution, suggesting a link with variations in solar output. Oceanic circulation may moderate the effects of TSI, but is likely influenced by variation in solar output itself, hence the correlations between TSI, the PDO, and the CET record.

The temperature variation in the CET record after the beginning of the Industrial Revolution can be explained changes in TSI in conjunction with a measure of greenhouse heating due to increasing atmospheric CO_2. Approximately two-thirds of climate warming since the mid-late 18th Century can be attributed to solar causes, suggesting warming due to anthropogenic causes over the last two centuries is 0.4 to 0.5°C.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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