The Canon Institute for Global Studies

CIGS Working Paper Series No. 19-008E

The Earth Climate System as Coupled Nonlinear Oscillators under Quasi-Periodical Forcing from the Space

(Revised Jan 15th 2020)

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2019.11
Revised 2020.1

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1 Introduction

Earth temperature changes with greenhouse gas (1), but there are other variations that are caused by Earth's internal system such as El Niño (2), as well as by effects from space such as fluctuation of the Solar intensity (3). Existing studies have considered either factors (1) and (2), or factors (1) and (3), but none have considered all three together. This paper presents a hypothesis that attempts to integrate all these factors.

Section 2 explains (1), section 3 explains (3) and section 4 deals with (2). Section 5 introduces a simple quantitative model, and section 6 attempts a qualitative synthesis of factors (1)-(3).

2 Greenhouse gas

Greenhouse gases such as CO_2 cause some change in the earth temperature. This, however, is insufficient to explain all the global temperature variation (IPCC, 2013).

3 Scafetta Theory: Spectrum decomposition of the global temperature variation

Scafetta (Scafetta, 2019); Scafetta (2016 , 2013) decomposed the annual average global temperature since 1850 into 6 cyclical natural variations and human induced global warming:

$$H(t)=h_{983}(t)+h_{115}(t)+h_{60}(t)+h_{20}(t)+h_{10.4}(t)+h_{9.1}(t)+\beta * m(t)+const, \qquad (1)$$

whereas $H(t)$ is the global temperature. $h_n(t)$ is a sine function with a cycle of n years. If $n=115$, for example,

$$h_{115}(t)=0.05\cos(2\pi(t-1980)/115). \qquad (2)$$

Each $h_n(t)$ is assumed that they have the same cycle as the fluctuation of the respective influences from space (such as the Sun). For example, solar energy forcing fluctuates with approximately 11-year cycle, which is accompanied by the fluctuation in the sunspot numbers. Other oscillation cycles correspond to tidal force fluctuation caused by the Sun's interactions with the moon and the planets.

$\beta *m(t)$ is the product of $m(t)$, which is the net greenhouse effect caused by greenhouse gasses as well as aerosols from volcano eruptions and other factors calculated by CMIP, and the parameter β. According to Scafetta's estimate, $\beta =0.5$. This is to say that half of the global warming during this period derives from net greenhouse effect caused by greenhouse gasses and aerosols, while the remaining half comes from the change in the effects from space on earth.

Scafetta argues that the results of formula 1 matches the actual historical data (Figure1), and that it is successful in recreating the hiatus. He also claims that applying the formula for past records, it produces a more realistic forecast results than the IPCC's ensemble projections (Figure 2).

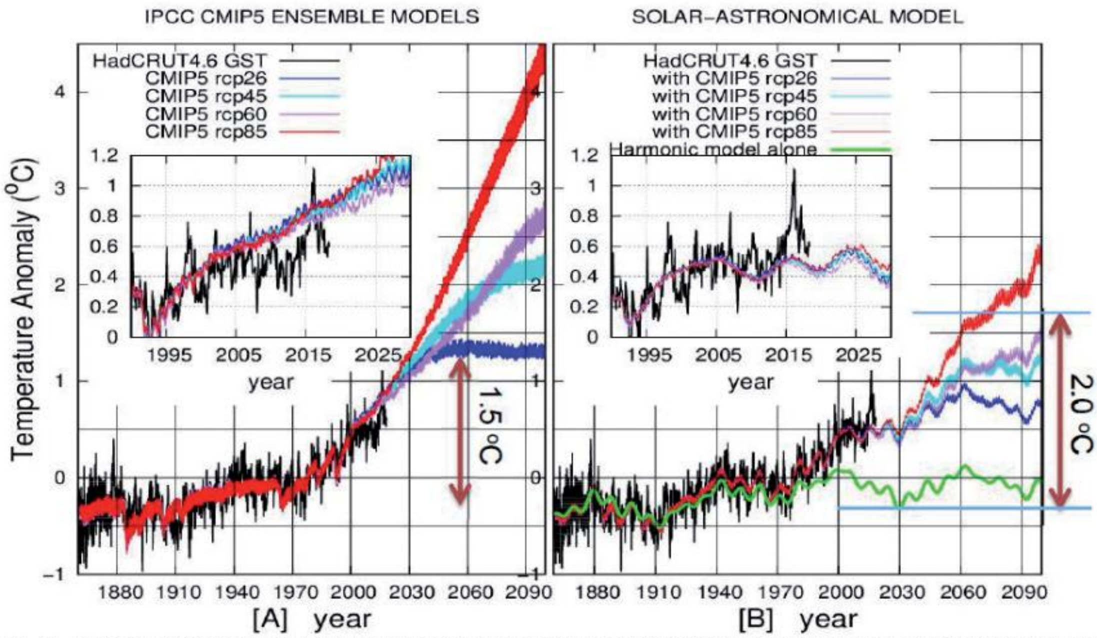

Fig. 18 - [A] The four CMIP5 ensemble average projections versus the HadCRUT4 GST record (black). [B] The solar–astronomical semi-empirical model. Updated from Scafetta *(2013a)*

Figure 1 Forecast of IPCC's ensemble models (CMIP5) and Scafetta's model. Taken from (Scafetta, 2019).

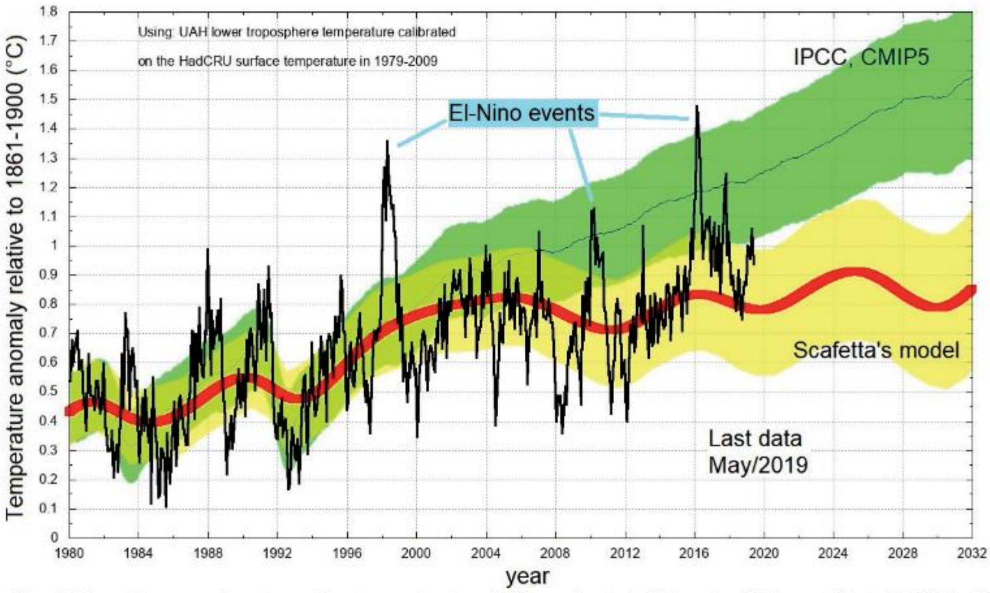

Fig. 19 - The global monthly average lower troposphere temperature since 1979 according to the University of Alabama at Huntsville (UAH), USA (black) up to May 2019 versus the CMIP5 ensemble average projections (green) versus the solar–astronomical semi-empirical model (yellow). The green and yellow areas have an equivalent 1-s uncertainty. Updated from Scafetta (2013a)

Figure 2 Comparison of forecasts by the CMIP5 ensemble model in IPCC (green) VS Scafetta model (red and yellow) . Scafetta argues his prediction was more accurate than that of IPCC. Taken from (Scafetta, 2019).

The issue with the Scafetta's argument is that currently, the mechanism to connect the astronomic effects to fluctuations in the global temperature is unclear.

For example, the approximately 11-year cycle of solar energy forcing fluctuation is well established, but the fluctuation itself is relatively small at about 0.2W/m^2. Svensmark (2018) argues that climate change is caused not only by the fluctuation of the solar energy, but also by the change in cloud formation, that are triggered by the shift in cosmic rays caused by the change in solar magnetic fields. This would increase the total fluctuation to 1.0 or 1.5 W/m^2 (Svensmark, 2018). But this is still controversial. Currently, the solar radiation and its magnetic field itself would be insufficient to explain any large portion of the climate change.

4 Tsonis Theory: Climate change as an interconnected oscillation

As an attempt to explain the natural variability of the climate since 1880, Tsonis proposed a theory of the climate system as an interconnected series of oscillations.

Tsonis identified five regimes (periods) in the Earth's temperature change since 1880, and considered the contributing factors for each of them (figure 4) (A. Tsonis, 2017)(A.

Tsonis, 2012).

Regime 1: 1880-1910, cooling

Regime 2: 1910-1943, rapid warming

Regime 3: 1943-1976, slow cooling

Regime 4: 1976-1998, rapid warming

Regime 5: 1998-, stagnation (hiatus)

Figure 3 shows that relative to the smoothed global temperature (represented by the curve), the actual temperature (bars) rise/fall with several years' interval. These are caused by various non-linear oscillation such as El Niño and Southern Oscillation (ENSO). Tsonis hypothesized that the multi-decadal temperature changes that caused the five regimes are a result of the interactions between these non-linear oscillations. In addition to ENSO, his hypothesis considers Pacific Decadal Oscillation (PDO), North Atlantic Oscillation (NAO), North Pacific Index (NPI). Tsonis argues that these non-linear oscillations are interconnected, and that the temperature trend significantly changed when these oscillations are synchronized and increasing the coupling with each other (the green period in the graph). Based on this hypothesis, a significant portion of recent warming might have come from factors other than GHG.

Tsonis also analyzed proxy record and argued that there are the oscillations internal to climate system ranging up to 1000 years[1](Anastasious A. Tsonis & Madsen, 2018). Furthermore, he argued that the models used in such as CMIP do not portray the climate system as a connected non-linear oscillation, which gives rise to some false stable climate state in the modelling process that are at odds with nature (Essex & Tsonis, 2018).

While the validity of this mechanism that Tsonis proposed may be debatable, the figure shows that the range of the multi-year-to-decadal oscillation can be quite large. It does seem plausible that interaction among these oscillations may give rise to significant temperature fluctuations on a multi-decadal scale that are totally different in their mechanism from greenhouse effects from GHG. Even if we are to reject this hypothesis, the question remains as to the nature of these five regimes of multi-decadal oscillations, especially the second regime where rapid warming occurred in spite of the low level of GHG emissions at the time.

Tsonis argues that there are three major players in climate change: natural variability such as the oscillations discussed above; human activity such as greenhouse gas effect, and; extraterrestrial (solar and cosmic rays) forcing. He also argues that current

[1] Tsonis also argued that there may still be natural oscillations with much longer time periods but the data availability cannot resolve them.

scientific knowledge is not enough to quantitatively decompose these three with confidence(Anastasios A Tsonis, 2020).

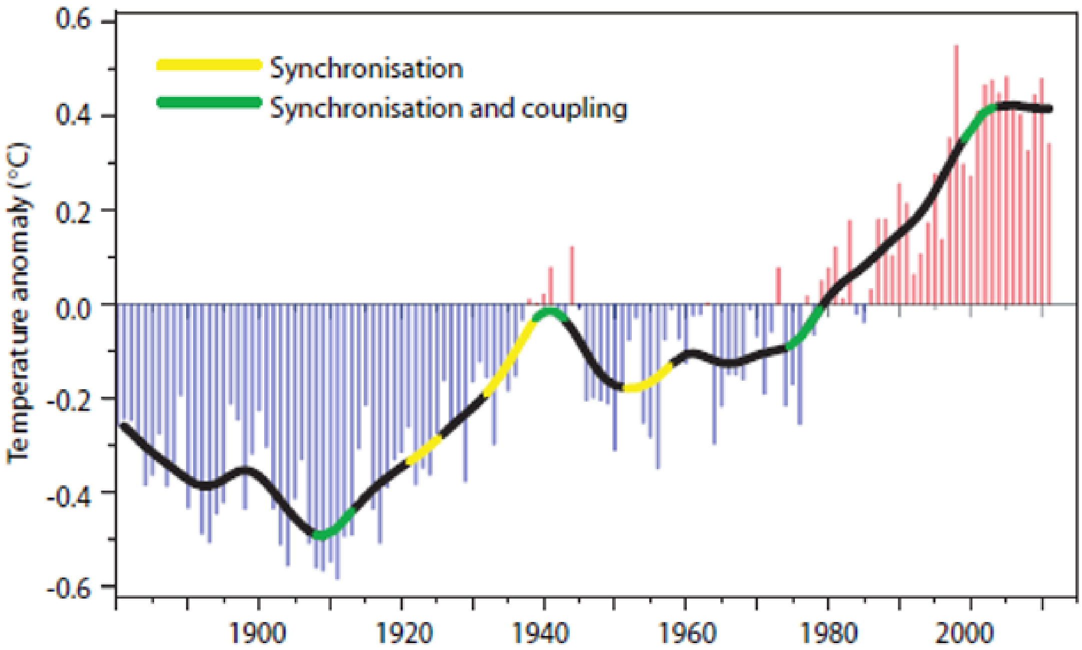

Figure 3 An attempt to explain the global temperature fluctuation during the 20th Century

Blue/red bars: observations, Solid line of black/yellow/green: smoothed observations. Yellow: Periods where oscillations synced. Green: Periods where oscillations synced, and strengthened their coupling. Taken from (A. Tsonis, 2017)(Anastasios A Tsonis, 2012)

5 Kuramoto Model: Interacting system of oscillators

Tsonis suggests that the global climate system may consist of multiple interacting oscillations. To gain further understanding, we consider a simplified model based on (Kuramoto 蔵本由紀, 2014), p103:

$$\dot{\theta}_i = \omega_i - \frac{K}{N}\sum_{j=1}^{N}\sin(\theta_i - \theta_j),\ i = 1,2,\ldots\ldots,N \qquad (3)$$

This is known as Kuramoto model, where N is the total number of oscillators in the group, θ_i the phase of the i th oscillator, and $\dot{\theta}_i$ is its speed of change. ω_i is the natural frequency of this oscillator, drawn randomly from a bell-curved distribution (normal distribution or Lorentz distribution). K is the coupling strength between the oscillators. The interaction between two oscillators is proportional to the sine function of the phase differential $\sin(\theta_i - \theta_j)$, and as the summation symbol Σ suggests, each oscillator receives the sum of the total interaction between all other oscillators. It is mathematically proven that below a certain threshold of K, group oscillation does not occur, while K above the threshold will cause group oscillation.

Figuratively speaking, when applied to the global climate system, θ_i would correspond to phases of the individual oscillations such as ENSO and AMO, while $\sin(\theta_i - \theta_j)$ corresponds to their coupling, and ω_i is the cycle of the i th oscillation.

Formula 3 is the well-studied Kuramoto model, which is known to show phase transitions. For example, if we consider R, the distance between the gravitational center of multiple particles and the geometric center of the circle, and describe it as a function of the coupling strength K (figure 4), it displays a phase transition as shown in figure 5. A video clip provides a good representation of such phase transition (http://idken.net/posts/2017-08-02-kuramoto/). For details of the Kuramoto model and Chaos theory, see (Strogatz 2014) (Kuramoto 蔵本由紀, 2016) (Kuramoto and Kawamura 蔵本由紀、河村洋文, 2017) (Strogatz, 2015).

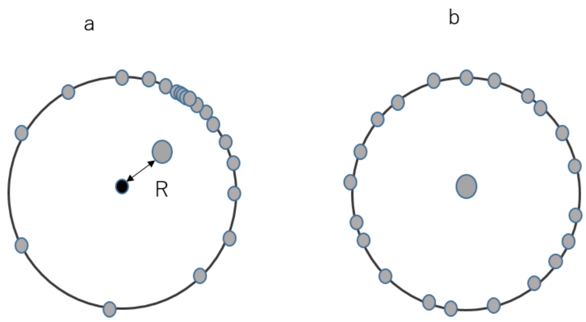

Figure 4 Geometric representation of the order parameter and group oscillation in a Kuramoto model (蔵本由紀, 2014) p103. When the distribution of the particles is uneven (panel a), group oscillation can be observed, but with an even distribution (panel b), no oscillation occurs. R, the distance between the gravitational center of the particles and the center of the circle, indicates the amplitude of the group oscillation.

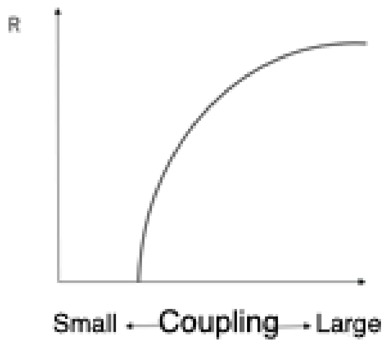

Figure 5 Phase transition in a Kuramoto model (Kuramoto 蔵本由紀, 2014) p104. Occurrence of group synchronization as a Phase transition. When the power of coupling K exceeds a threshold, R, which indicates the amplitude of the group oscillation, suddenly jumps up from zero, i.e. a group oscillation suddenly occurs.

6 The Earth Climate System: Coupled Non-linear Oscillators under Quasi-Periodical Forcing from the Space

In Kuramoto model, there is no external forcing to the oscillators. But Scafetta theory suggests that astronomic effects such as changes in solar activity serve as pseudo-periodical forcing[2]. Under a periodic external forcing, a chaos system tends to sync with the forcing with m/n times the external cycle, with m,n being a natural number (Kuramoto 蔵本由紀, 2014) p154. The actual climate system is not a pure harmonic oscillator. It displays internal quasi-periodic oscillations with chaotic properties. Even between such chaotic systems, it has been demonstrated that synchronizations occur (Strogatz, 2014) Ch.7.

Based on the insights gained by the above discussions, the following hypothesis about the global climate system can be presented:

1. The climate system, in the absence of astronomic forcing other than a fixed solar radiation, includes numerous quasi-periodic oscillations with cycles from very short term to several hundred years.
2. Some of these oscillations are excited to create oscillations with cycles of several years to several centuries.

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[2] A note about the terminology. This paper describes various oscillations in the Earth's climate system such as ENSO as quasi-periodic. It means that the activity seems mostly periodic, but it isn't precisely periodic. Such use is common in the field of climate studies. Readers should be aware that the term may have a different meaning in other disciplines such as mathematics and material physics.

3. The external forcing that drives this excitation would include quasi-periodic fluctuations of effects from space to earth, such as the quasi-periodic oscillation of about 11 years that are found in sunlight intensity.
4. The advantage of this hypothesis is that the change in the solar activity in itself does not need to be large enough to directly cause the Earth's quasi-periodic climate change.[3]

To elaborate on the last point, this is similar to riding a swing. Small kick for each cycle would add up and eventually lead to huge swings.

Scafetta and Svensmark claimed that astronomic effects on Earth, such as changes in solar activity, drives the quasi-periodic oscillation of climate change. The difficulty of such argument is that the solar intensity and the fluctuation of cosmic rays caused by the change in solar magnetic fields are too weak in themselves to cause the observed climate change. However, if these forcing serves as the driver to excite the oscillations, then the direct effect themselves can be small.

While the fluctuation in solar intensity may not be large, it is strong enough to cause clear changes in the global climate system. For example, the annual average temperature in Hokkaido of Japan has fluctuated for more than 0.5 degrees over the years. It is argued that this is synchronized with the 11 year cycle of sunspots (Kondo 2010 近藤 純正, 2010). The possible mechanism to excite this oscillation might be through changes in visible light, or changes in the magnetic fields, or fluctuations in UV rays, but still unclear.

A word about the greenhouse effect. The hypothesis of the climate system here does not deny the warming caused by GHG such as CO_2. For this climate system, GHG serves as a non-cyclical forcing. For example, CO_2's greenhouse effects will generally appear as the log function of its concentration. However, the magnitude of its indirect effects, such as feedbacks caused by water vapor and clouds is uncertain. IPCC (2013) sets the climate sensitivity at 1.5-4.5℃ with 66 percent confidence interval, based on expert judgement.

If much of the observed warming in the past was caused by oscillations unrelated to greenhouse effects, a low-end climate sensitivity would be suggested. This is the position taken by Scafetta. But theoretically, the opposite may also be possible. Greenhouse effects in the past may have been offset by some independent oscillations. In such case, climate sensitivity may be at the high-end.

[3] This argument is already made by (Scafetta, 2010)

By the way, it is fundamentally difficult to determine whether a long-term warming trend of over 100 years is a long cycle oscillation ($h_{983}(t)$, $h_{115}(t)$, $h_{60}(t)$ in Scafetta's equation) or the effect of GHG. For example, how much of the warming since 1850 is an oscillation that reflects the recovery from the little ice age, and how much of it is caused by GHG.

A word about future studies. First, the room for analytical treatment of this hypothesis would be limited. While various analysis such as the Kuramoto model has been made by Chaos theory experts, they are nowhere near the intricacies of the climate system as shown in section 6. Testing this paper's hypothesis using GCMs would likely be unfeasible for the foreseeable future, due to lack of model resolution and observed data. It would be worthwhile to strengthen various satellite observations, or studies of paleoclimates. Detailed understanding of oceanic and atmospheric heat movements would provide useful suggestions. As experiments, one can create a Chaos system that displays a quasi-periodic oscillation using op-amps or plasmas. Such systems can be coupled to see their behavior. This has also been done in the study of Chaos theory. Whatever the method, the hypothesis presented in section 6 should be taken into account (which, of course, may lead to its rejection). Theory as a framework, although sometimes a hindrance, may assist in creating guidelines for observations and experiments, or interpretation of their results. As the saying goes, "if you don't believe that it exists, you can't see it"[4].

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