DOI: 10.4408/IJEGE.2019-01.O-05

ON THE RELIABILITY OF COMPUTER-BASED CLIMATE MODELS

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EXTENDED ABSTRACT

Dal 1850 il clima della Terra si è riscaldato di circa 0.9°C, e di circa 0.5°C dal 1950. Questo fenomeno è noto come il Global Warming. Simultaneamente, la concentrazione atmosferica di alcuni gas-serra, principalmente dell'anidride carbonica (CO_2) prodotta dalla combustione dei combustibili fossili (carbone, metano, e derivati del petrolio), è aumentata. Ci si chiede, quindi, quanto l'uomo abbia contribuito a questo cambiamento climatico, e cosa potrebbe succedere in un futuro prossimo. Le risposte a queste domande determinano una serie di programmi che le società del mondo dovrebbero attuare. Se i cambiamenti climatici prossimi fossero significativi e dannosi, sarebbe necessario mitigarli sin d'ora: cosa che, però, comporterà gravi oneri economici perché significherebbe rinunciare ai benefici dei combustibili fossili. Se, al contrario, nei prossimi decenni il clima cambierà moderatamente, sarà sufficiente adattarsi ad esso.

Usando modelli climatici dinamici, come i General Circulation Models (GCMs), l'Intergovernmental Panel on Climate Change (IPCC) delle Nazioni Unite ritiene che i forzanti antropici siano stati gli unici responsabili (cioè al 100%) del riscaldamento osservato dal periodo pre-industriale (1850-1900) ad oggi. L'argomento proposto è che i forzanti naturali (variazioni nell'irragiamento solare e le eruzioni vulcaniche) da soli non sarebbero stati in grado di produrre nessun riscaldamento dal periodo pre-industriale, e neppure dal 1950 ad oggi. Questi stessi modelli prevedono un riscaldamento climatico di oltre 1.5°C dal 2030 e di 4-5°C entro il 2100, rispetto al 1850-1900, se le emissioni di CO_2 non saranno drasticamente e immediatamente ridotte. Questi scenari climatici sono stimati pericolosi per l'ambiente e le società umane.

Tuttavia, sono affidabili questi GCMs? Per testarlo occorre dimostrare che essi siano in grado di ricostruire correttamente i climi del passato. Tuttavia, i GCMs non riescono a ricostruire adeguatamente la variabilità naturale del clima durante gli ultimi 10000 anni, noti come l'Olocene, e su più scale temporali. In modo particolare essi non ricostruiscono: (1) il lungo periodo caldo noto come l'Holocene Climatic Optimum (9000-6000 anni fa) con il successivo raffreddamento osservato da 5000 anni fa ad oggi; (2) le grandi oscillazioni millenarie dell'Olocene le cui fasi calde comprendono, ad esempio, il Periodo Caldo Medievale e, mille anni prima, il Periodo Caldo Romano; (3) diverse oscillazioni climatiche più brevi con periodi di circa 9.1, 10.4, 20, e 60 anni; (4) la tendenza del riscaldamento globale dal 2000 ad oggi, che i GCMs sovrastimano per almeno un fattore 2.

Le implicazioni fisiche di questi risultati sono due: (1) la sensibilità climatica all'equilibrio (SCE) dei GCMs al forzante radiativo (misurato come un raddoppio di CO_2 atmosferico) è sovrastimata in media per un fattore 2 (numerosi studi recenti suggeriscono una SCE realistica tra 1°C e 2°C); (2) esistono forzanti climatici solari e astronomici che sono ancora incerti o sconosciuti e che, quindi, mancano nei GCMs. Probabilmente questi forzanti modulano direttamente il sistema nuvoloso e/o le oscillazioni oceaniche che sono i principali meccanismi che inducono i cambiamenti climatici. Quindi, gli attuali GCMs sovrastimano notevolmente il contributo antropico mentre sottostimano quello naturale. Essi non sono sufficientemente sviluppati per interpretare e prevedere i cambiamenti climatici con una soddisfacente affidabilità scientifica.

L'alternativa è usare modelli climatici semi-empirici presenti nella letteratura scientifica ma ignorati dall'IPCC. Questi non hanno la pretesa di ricostruire tutti gli aspetti climatici come i GCMs, ma possono essere più affidabili per compiti specifici. Questi tipicamente modellano che la variabilità solare abbia contribuito almeno il 50% del Global Warming dal 1850-1900 ad oggi. Inoltre, i dati mostrano una variabilità climatica naturale costituita da diverse oscillazioni (con periodi di circa 9.1, 10.4, 20, 60, 115, 1000 anni, ed altri) che sono coerenti con note oscillazioni solari, lunari e astronomiche. I modelli che utilizzano queste oscillazioni insieme ad un contributo antropico e vulcanico (uguale però alla metà di quello prodotto dai GCMs) riproducono ottimamente la variazione climatica osservata sin dal 1850 ad oggi. Inoltre, essi predicono un riscaldamento piuttosto moderato da 2000 al 2040 e un riscaldamento di circa 2°C dal 2000 al 2100 utilizzando gli stessi scenari di emissione antropici utilizzati per le simulazioni climatiche del XXI secolo dei GCMs.

I risultati empirici suggeriscono che le politiche di adattamento, che sono molto meno costose di quelle di mitigazione, saranno sufficienti per affrontare i cambiamenti climatici che potrebbero verificarsi nel XXI secolo.

ABSTRACT

Since 1850 the global surface temperature of the Earth has warmed by about 0.9°C. The computer climate models adopted by the Intergovernmental Panel on Climate Change (IPCC), such as the General Circulation Models of the Coupled Model Intercomparison Project Phase 5 (CMIP5), projected that the global surface temperature could rise more than 1.5°C by 2030 and more than 4-5°C by 2100 relative to the pre-industrial period (1850-1900) because of anthropogenic greenhouse gas emissions. These computer projections are being used to justify expensive mitigation policies to drastically reduce CO_2 emissions due to the use of fossil fuel. However, these models must be validated before their interpretation of climate change could be considered reliable. Herein, I summarize recent scientific research pointing out that these GCMs fail to properly reconstruct the natural variability of the climate throughout the entire Holocene and at multiple time scales such as: (1) the Holocene Climatic Optimum (9000-6000 years ago) with the subsequent cooling from 5000 years ago to now; (2) the large millennial oscillations observed throughout the Holocene that were responsible, for example, for the Medieval Warm Period; (3) several shorter climatic oscillations with periods of about 9.1, 10.4, 20, 60 years; (4) the climate change trend after 2000 to date, which the models greatly overestimate; and many other patterns. These different pieces of evidence imply two main facts: (1) the models' equilibrium climate sensitivity (ECS) to radiative forcing, such as to an atmospheric CO_2 doubling, is overestimated at least by a factor of 2, which implies a more realistic ECS between 1°C and 2°C; (2) there are a number of solar and astronomical forcings that are still missing in the models or are poorly understood yet. Consequently, these GCMs are not physically reliable for properly interpreting past and future climatic changes. Alternatively, semi-empirical climatic models should be used. Data analysis found that the climatic natural variability is made of several oscillations from the decadal to the millennial scales (e.g. periods of about 9.1, 10.4, 20, 60, 115, 1000 years) and others. These oscillations are coherent with solar, lunar and astronomical oscillations. A semi-empirical climate model that makes use of these oscillations plus a reduced ECS reconstructs with great accuracy the climate variability observed since 1850 and projects a very moderate warming until 2040 and a warming lower than 2°C from 2000 to 2100 using the same anthropogenic emission scenarios used for the 21st-century climate simulations of the CMIP5 models. This result suggests that climatic adaptation policies, which are far less expensive than the mitigation ones, could be sufficient to address the consequences of climatic changes that could occur during the 21st century.

***Keywords:** climate change, global warming, general circulation models, solar-climate interactions, validation tests*

INTRODUCTION

Since the pre-industrial period (1850-1900), the global surface temperature of the Earth has warmed by about 0.9°C, and since the 1950s by about 0.5°C (Fig. 1, black curve). This warming has occurred during a significant increase in the atmospheric concentration of some greenhouse gases (GHG), especially CO_2, mainly induced by anthropogenic emissions because of fossil fuel burning. According to the interpretation of numerical climate models - e.g. the Coupled Model Intercomparison Project Phase 3 and 5 General Circulation Models (CMIP3 and CMIP5 GSMs) - adopted by the Intergovernmental Panel on Climate Change (IPCC, 2013), anthropogenic emissions should be considered responsible for nearly the totality (100%) of the warming observed since the pre-industrial times. In fact, in the latest report of the IPCC (2018) it is clearly stated that "*Human activities are estimated to have caused approximately 1.0°C of global warming above pre-industrial levels, with a likely range of 0.8°C to 1.2°C*", while the "*observed global mean surface temperature (GMST) for the decade 2006–2015 was 0.87°C (likely between 0.75°C and 0.99°C) higher than the average over the 1850–1900 period*". Thus, anthropogenic emissions are claimed to have caused essentially 100% of the observed warming.

This result is derived from the computer simulations shown in Figure 1. Here the computer experiments are run in two different situations. In the first case, only natural climatic forcings are used. These are the result of solar and volcano deduced radiative forcings. The results are plotted in Fig. 1A and show that natural forcing alone would have produced virtually no warming from 1870 and 2010 since the ensemble mean computer simulations (red and blue curves) show nearly the same temperature anomaly level, about 0.2°C, in 1860-1880, 1940-1960 and 2000-2015. Thus, this computer experiment implies that natural forcing alone could not have caused any warming during the last 150 years. On the contrary, Figure 1B shows that when all forcing functions are used, that is when natural and anthropogenic forcings are considered together, the models roughly reproduce the 0.9°C warming observed since 1860. This computer experiment is interpreted as if only anthropogenic forcing can explain the observed warming. This is the reason why the observed global warming has been classified as *anthropogenic* (IPCC, 2013).

The same climate models are then used to obtain global climate projections for the 21st century according to alternative representative concentration pathway (RCP) emission scenarios (measured in CO_2 equivalents; see Fig. 2). There are four different scenarios: RCP 2.6 assumes that the global annual GHG emission peaks between 2010-2020, with emissions declining after that. RCP 4.5 assumes an emission peak around 2040, then decline. In RCP 6.0, emissions peak around 2080, then decline.

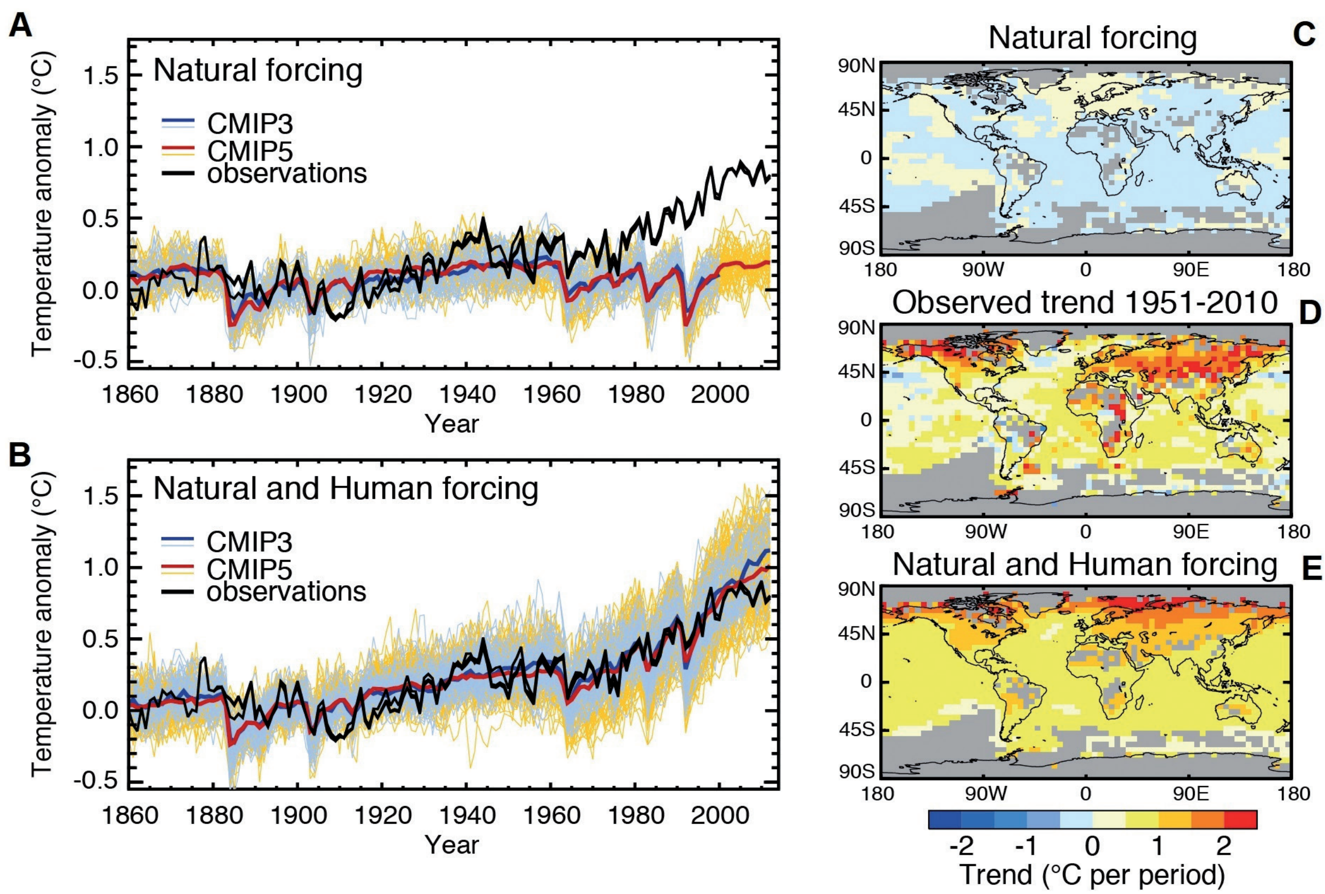

Fig. 1 - Observed global surface temperature variation (black) and the CMIP3 and CMIP5 computer model simulations using natural forcing alone and natural and human forcing. Source IPCC (2013), FAQ 10.1. According to these models, natural forcing alone would not have induced any warming from 1870 to 2010. The observed warming was 100% anthropogenic

In RCP 8.5, emissions continue to rise throughout the 21st century. As Figure 2 shows, if CO_2 emission is not substantially mitigated, e.g. if it follows the 8.5 RCP scenario, the global surface temperature would rise up to about 4-5°C above the 1860-1900 pre-industrial period and will continue to rise in the following centuries (IPCC, 2013, 2018).

The IPCC (2018) concludes that global surface warming is likely to reach 1.5°C above the pre-industrial period roughly around 2030 if it continues to increase at the current rate predicted by the models. If such warming occurs by the above date, it could potentially endanger human societies because of the impossibility to adapt to the too rapid sea level rise, to an increase of extreme weather events, to threatened ecological systems, etc. Therefore, these computer climate model projections are used to justify expensive mitigation policies to significantly reduce the emission of anthropogenic greenhouse gases to keep the global surface warming below 1.5/2.0°C relative to the pre-industrial period for as long as possible. This understanding of the climate system and its changes is known as the *Anthropogenic Global Warming Theory* (AGWT) which has been widely advocated by the IPCC at least since 2001.

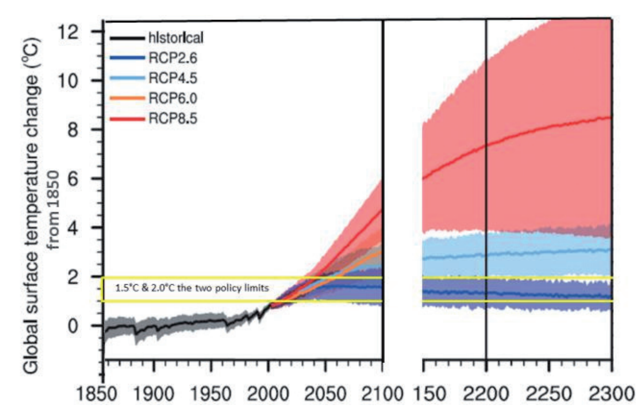

Fig. 2 - Projected global surface temperature warming of the CMIP5 computer model simulations using different representative concentration pathway (RCP). Source IPCC [1]

However, any physical models must be validated to be

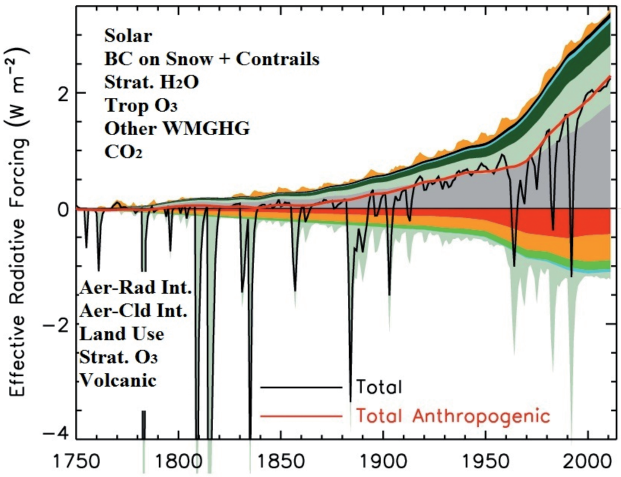

Fig. 3 - Top to bottom: list of radiative forcing functions used in the numeric general circulation models (IPCC, 2013)

considered a valid representation of a natural system. Thus, also the GCMs used to interpret climate change need some robust validation evidence. In the eventuality that the validation fails, their projections for the 21st century would not be reliable. Thus, it is fundamental to clarify this issue also because there is an increasing body of evidence that both the CMIP3 and CMIP5 GCMs models fail to properly reconstruct natural climate variability at multiple time scales, and that they significantly overestimated the climatic effects of the anthropogenic emissions (e.g. Idso *et alii*, 2013; 2016). Because a twin Earth without humans is not available for a direct experimental comparison, the only way to validate a climate model is to test whether it properly predicts the climatic changes of the past at multiple time scales.

In this short review, I will briefly summarize some of the main reasons why the AGWT should be questioned. A reader should consider that a recent survey among more than 4000 members of the American Meteorological Society (Maibach *et alii*, 2016) revealed that 96% of the respondents acknowledges that a climatic change is taking place. However, with regards to its physical causes, only 29% of respondents agreed with the claim that 80-100% of the global surface warming observed since 1960 has been induced by human activity. Another 38% claimed that humans were responsible for 60-80% of the observed warming, while 26% claimed that natural climatic factors have contributed from 40% to 100% of it. 6% could not answer and only 1% thinks that a climatic change did not really occur. So, only a minority, probably far less than a third of the US meteorologists agrees with the claim of the IPCC that the totality (100%) of the warming observed since 1870 or 1960 has been anthropogenic. Thus, it is not true that there is a nearly total consensus on the IPCC's main claims. I will try to explain why so many people with some expertise on this topic are skeptical of the AGWT of the GCMs.

In addition, I will present an alternative interpretation of climate change based on semi-empirical climate models that are discussed in the scientific literature but ignored by the IPCC. This alternative interpretation of climate change is based on the evidence that the Earth's climate is driven by specific natural oscillations and by a reduced anthropogenic and volcanic effects. The modeling resulting from these considerations appears also to agrees better with the data and is likely more reliable than the GCMs' global climate change forecasts (e.g. Scafetta, 2013a; 2013b).

THE UNCERTAINTY IN THE EQUILIBRIUM CLIMATE SENSITIVITY TO RADIATIVE FORCING

The GCM modeling of the climate relies on a complex set of coupled differential equations describing the circulations of the atmosphere and the ocean of various climatic phenomena, and on a set of external radiative forcings functions influencing the system such as those depicted in Fig. 3. If the forcing functions were constant, the climatic system would at most fluctuate around a mean value as a correlated red noise. Therefore, the time evolution of the forcing functions is required to induce a climatic change in a sufficiently long period. Determining the correct forcing functions of the system is one of the main scientific issues because it is not possible a priory to know whether all forcing functions are already known.

For example, the GCM forcing functions depicted in Figure 3 suggest that the solar forcing has been nearly negligible. However, there are two main open issues here: 1) the secular variability of the total solar irradiance forcing is still highly debated because some records show a secular variability as low as 0.6 W/m^2 since 1700 to present (Wang *et alii*, 2005) while others show a very large secular variability up to 6 W/m^2 during the same period (Egorova *et alii,* 2018); 2) there are several indications that the sun induce climatic changes through a cosmic ray forcing that could directly modulate the cloud system (Kirkby, 2007; Svensmark *et alii*, 2017). This would be a different kind of solar related forcing that is completely missing in the GCMs.

The typical forcing functions used in the CMIP5 climate models are those deduced from the changes of atmospheric GHG concentrations such as CO_2, CH_4, etc., of atmospheric aerosol concentration, of land use change, of volcanic aerosol, of total solar irradiance (which was deduced from Wang *et alii*, 2005 that minimizes in the GCMs the solar effect on climate) and others. Figure 3 summarizes the forcing functions for the historical period from 1750 to 2005 used in the CMIP5 GCMs. An additional implicit claim made by the IPCC is that with the exception of the solar and volcanic forcings, all other forcings have an anthropogenic origin. This claim, however, is likely incorrect because also natural climatic changes can induce GHG changes in the atmosphere. In fact, the release or absorption of CO_2 by the ocean depends on its surface temperature. It should be specified that water vapor (H_2O) is the most important of the GHGs, but it is not included among the GCMs forcings because it is a feedback of the system whose evolution, like that of the clouds, is directly calculated by the physical equations of the models.

The most important climatic parameter is the equilibrium climate sensitivity (ECS) to the radiative forcing which measures the warming at equilibrium caused by doubling the amount of atmospheric CO_2. The CMIP3 and CMIP5 GCMs and a number of other empirical and numerical studies estimate that if the CO_2 atmospheric concentration doubles (for example, from the 280 ppm preindustrial level to 560 ppm), the climate system could warm roughly between 1°C and 5°C (Lewis, 2013; Knutti *et alii*, 2017). Figure 4 compares a number of these climate sensitivity estimates.

The first problem is the very large ECS uncertainty. It implies that the same radiative forcing could theoretically cause a warming ranging from a given minimum value to a five times larger value. This uncertainty is mostly due to the poor ability of the models to reproduce the various climatic feedbacks, including the modeling of the water vapor and the cloud system.

However, numerous recent studies have pointed out that the ECS of the GCMs is very likely overestimated and that a more realistic range could span between 0.75 and 2.25°C with an average of 1.5°C (e.g.: Scafetta, 2013a; Gervais, 2016; Lewis & Curry, 2015; 2018). This is half of the mean ECS of the CMIP3 and CMIP5 models, which is around 3°C. In fact, also Knutti *et alii* (2017), who reviewed the literature on this topic acknowledged that: "*...evidences from climate modelling favours values of ECS in the upper part of the likely range, whereas many recent studies based on instrumentally recorded warming - and some from paleoclimate - favour values in the lower part of the range.*" Thus, a GCMs-data discrepancy is becoming more and more evident.

This result indicates that the real climate sensitivity to radiative forcing, as determined now by several authors, could be about half, or even a third (e.g.: Lindzen & Choi, 2011; Bates, 2016) than what calculated and implemented by the GCMs used by the IPCC on which the simulations shown in Figures 1 and 2 are based. A low ECS would question the objectiveness of the IPCC (2001; 2007; 2013, 2018) scientific conclusions such as their interpretation of the warming observed in the 20th century and their 21st-century climatic projections. In fact, if the real ECS is about half or less than what the GCMs implement, then the anthropogenic warming predicted by such models should be at least halved as well, and, with such low ECS those models would not be able to reproduce the warming observed since 1850-1900 using the same forcings depicted in Figure 3.

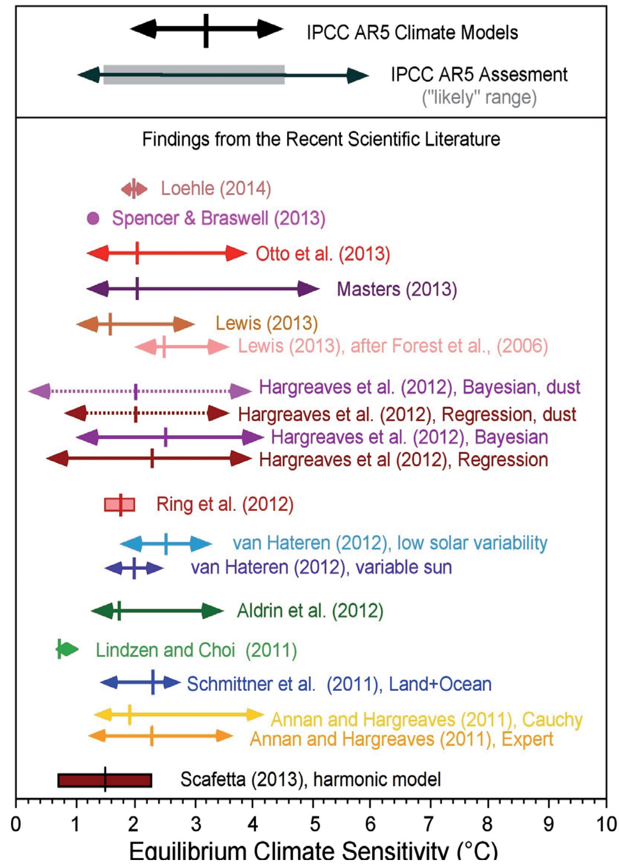

Fig. 4 - Comparison among estimates of the climate sensitivity to the radiative forcing induced by a doubling of atmospheric CO_2 concentration (cf. IPCC, 2013; Scafetta, 2013; Lewis, 2013). Note the large uncertainty

Therefore, if the ECS is as low as several recent studies have shown, different or additional forcing functions should be considered. For example, there might be the need for using different solar forcing functions showing a much larger secular variability and several other climate issues should be investigated further.

EVIDENCE FOR A LARGE NATURAL VARIABILITY NOT REPRODUCED BY THE GCMs

There are several empirical evidences that the climate models used to support the AGWT fail macroscopically in reproducing observed climatic variations throughout the entire Holocene from 10000 years ago to present times. Regarding the previous period, Shakun *et alii* (2012) showed that global warming preceded changes in carbon dioxide concentrations during the last deglaciation and, therefore, the CO_2 atmospheric concentration behaved as a feedback by varying as a response of the varying climate induced by orbital variations. Let us now discuss some of the main cases referring to the Holocene.

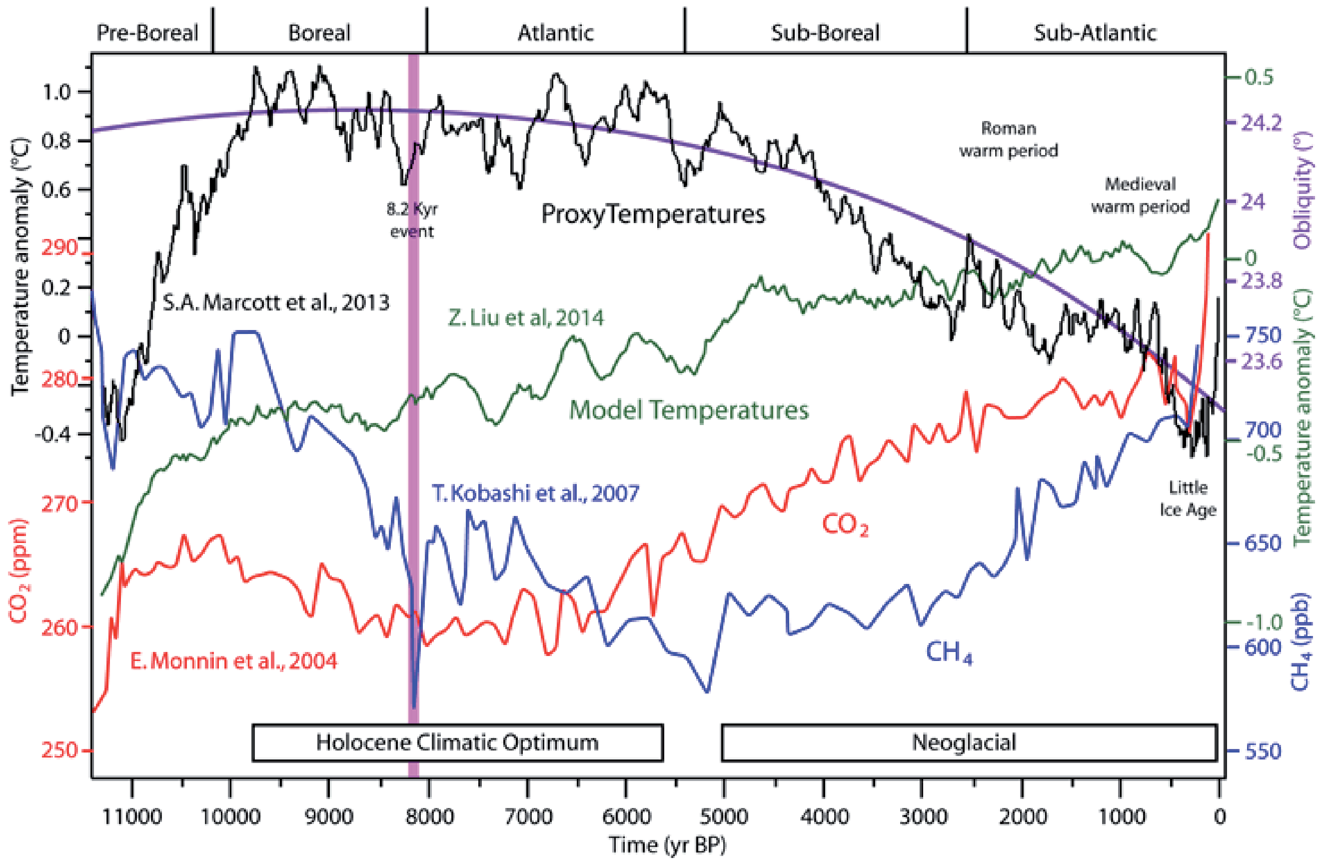

Fig. 5 - Proxy temperature (black), climate model temperature reconstruction (green), evaluated CO_2 and CH_4 atmospheric concentrations (red and blue curves) and insolation obliquity forcing (purple). Source Javier (2017). Note that the temperature decreases while the computer models show a temperature increase during the Holocene

The Holocene Period

The temperature reconstructions of the Holocene (Alley, 2004; Shakun *et alii*, 2012; Marcott *et alii*, 2013) suggest a quite warm period known as the Holocene Climatic Optimum from about 9500 to 5500 years ago. After this period the temperature cooled about on average 1.0°C. However, the climate models, by being oversensitive to CO_2 concentration, predicted a continuous warming by about 1°C during the entire period.

Figure 5 shows the Holocene temperature record by Marcott *et alii* (2013) in black against a typical computer model simulation (see Liu *et alii*, 2014) against the evaluated atmospheric concentration of two greenhouse gas records used as forcings in the climate models: CO_2 (Monnin *et alii*, 2004) and CH_4 (Kobashi *et alii*, 2007). The figure demonstrates that, while the temperature record shows an evident cooling from the Holocene Optimum to present times mostly induced by the orbital forcing linked to the changes in insolation due to variation of the obliquity of the Earth's axis (purple curve), the climate models (green curve) mostly show a continuous warming of about 1°C from 10000 years ago to present by closely following the observed increase in CO_2 (red curve) and CH_4 (blue curve). Liu *et alii* (2014) commented on the severe data-model discrepancy by concluding that if the climate data are correct, the result implies the existence of "*major biases across the current generation of climate models*".

To check whether the problem relies upon the data, Figure 6 shows and compares the temperature reconstruction of the Holocene obtained from the GIPS2 ice core record in Greenland (Alley, 2004) and from climate proxies of the European Alps (Kutschera *et alii*, 2017). These independent records confirm the Holocene Climatic Optimum from about 9500 to 5500 years ago when, for example, the glaciers on the European Alps were often significantly smaller than present times. Besides, these records also reveal a large quasi millennial oscillation that lasts nearly for the entire period of 10000 years. This oscillations characterized, for example, the Minoan warm period (nearly 3000 years ago), the Roman warm period (nearly 2000 year ago), the Medieval Warm period (nearly 1000 year ago) and now the temperature is nearly compatible or slightly lower

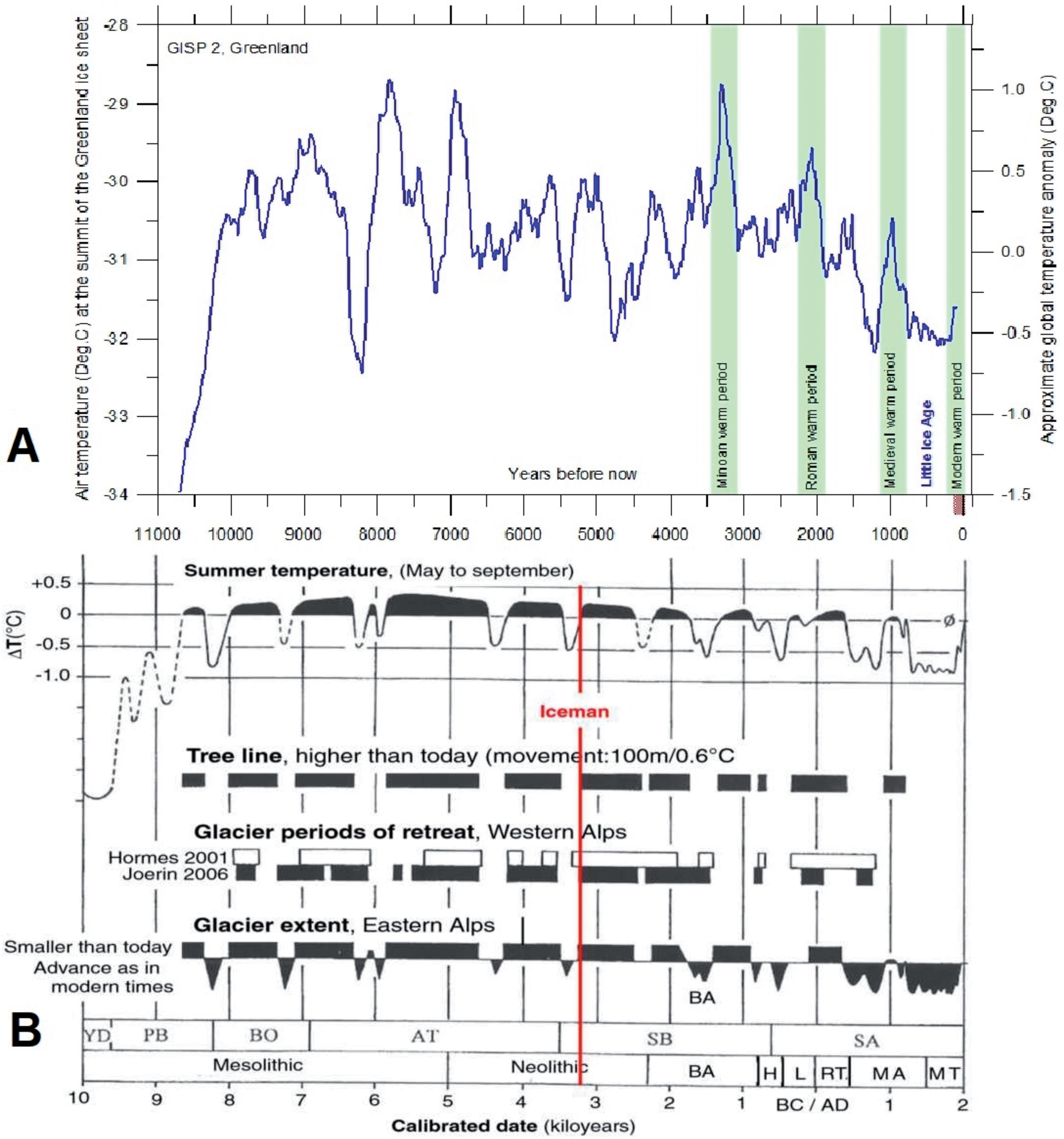

Fig. 6 - [A] Holocene temperature record from GIPS2 (Alley, 2004) and [B] the Summer temperature and other climate records referring to the Alps (Kutschera et alii, 2017). The red line indicates the dating of the iceman, Ötzi, found in the Ötztal Alps in 1991 at an elevation of 3210 m

than during the medieval times when the Alps' glaciers were slightly smaller than today. In this regards, a recent study has determined that during the Middle Ages the Vikings enjoyed a Greenland warmer than today (Lasher & Axford, 2019). Thus, the Holocene data patterns appear to be robust and the result depicted in Figure 5 demonstrates a severe failure in the models. Figure 5 also shows that the climate models do not reconstruct the observed large millennial oscillation too because the

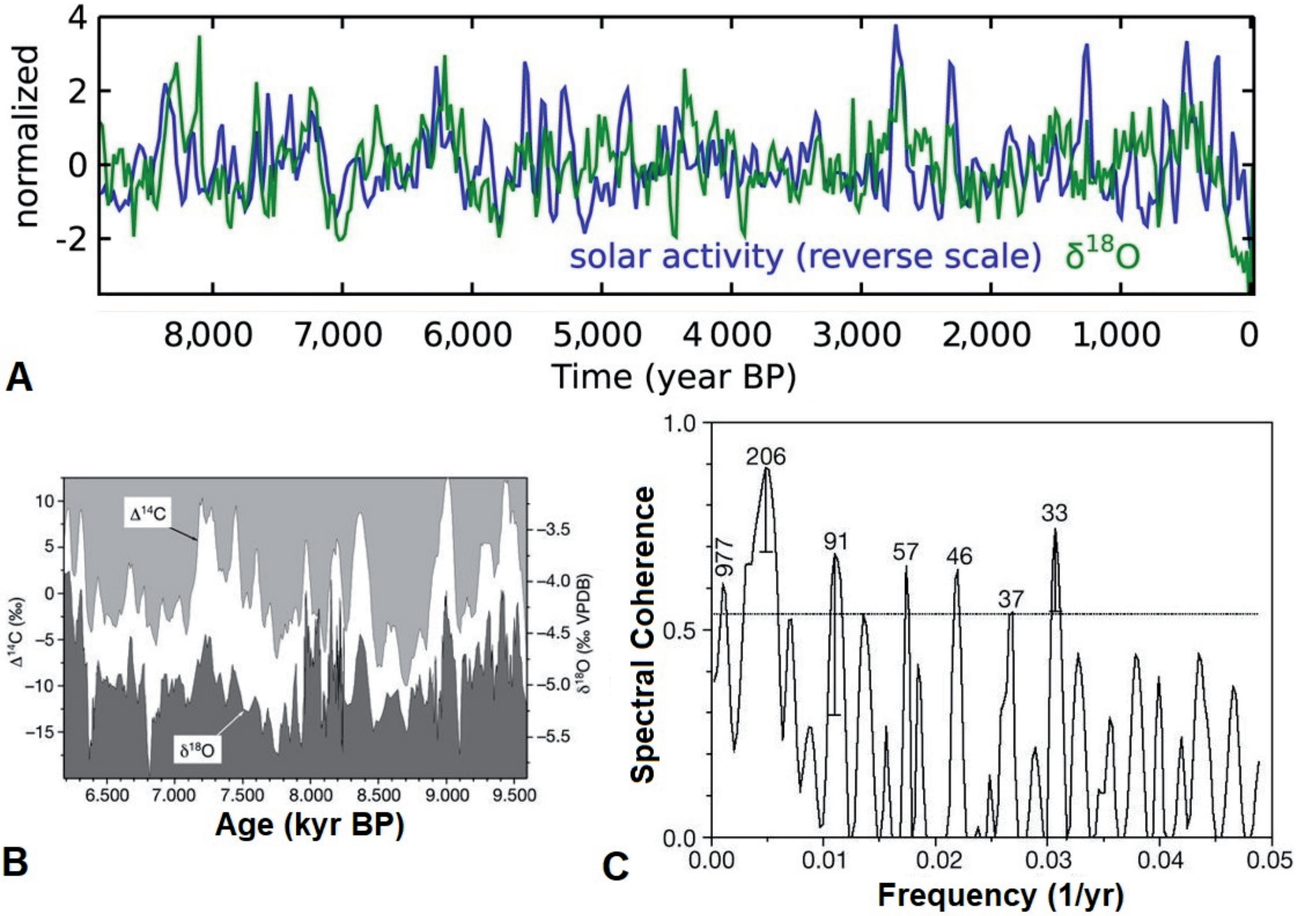

Fig. 7 - [A] Evidence for a high correlation between a solar activity record in blue based on cosmic ray flux and a δ¹⁸O record from Dongge cave, China, in green representing changes of the Asian climate (Steinhilber et alii, 2012). [B] Solar variability (C14) and the monsoon record in Oman between 9000 and 6000 years ago; [C] spectral coherence between the two records (Neff et alii, 2001)

CO_2 and CH_4 records do not show those oscillations. On the contrary, Figure 7 shows that the Holocene climate variability and its large millennial climatic oscillation is far better correlated with solar activity and cosmic ray flux variation indexes such as 14C and 10Be isotope records than with CO_2 or other GHGs records (Bond *et alii*, 2001; Kerr, 2001; Steinhilber *et alii*, 2012; Kirkby, 2007). Neff *et alii* (2001) also demonstrated a strong spectral coherence between solar variability and the monsoon record in Oman between 9,000 and 6,000 years ago: see Figure 7B and 7C. In particular, Figure 7C demonstrates that solar and climate records present common spectral peaks at typical frequencies known in the scientific literature as the Eddy cycle (800-1200 yr), Suess-de Vries cycle (200-250 yr), Gleissberg cycle (80-100 year), the 55-65 yr spectral cluster and others. All these harmonics can be deduced from astronomical orbital periods (Scafetta, 2012c; Scafetta *et alii*, 2016).

In conclusion, multiple records demonstrate that the Holocene, that is the interglacial period of the last 11700 years, was characterized by a warm period from about 9500 to 5500 years ago and has been cooling after that for the last 5500 years because of insolation changes due to the evolution of the obliquity of the Earth's axis. However, it is equally evident that the known variations in greenhouse gases are unable to explain the Holocene climatic changes and its quasi millennial oscillations. It is even observed that CO_2 and CH_4 concentration changes are negatively correlated to temperature trends for most of the Holocene.

In conclusion, the climate models are shown to perform very poorly when trying to reproduce the Holocene climate changes: they follow more closely the monotonic increase in greenhouse concentrations than the orbital insolation forcing and other solar forcings that correlate far better with the temperature records. All this confirms that the models have a too high sensitivity to changes in greenhouse gases . Simultaneously, they poorly model the real climatic effects of the orbital and solar forcings.

The last 1000 years, from the Middle Ages to today

Comparing climate records and model simulations from 1000 AD to 2000 AD is very instructive because explains in part the present popularity of the AGWT. In brief, around 2000 it was claimed that the climate models had been sufficiently validated and this claim, which today cannot be considered valid anymore, has been widely popularized until our days (for example, by the "*Inconvenient Truth*", the popular 2006 documentary by Al Gore) with the repeated claims that "*the debate is over*", "*the science is settled*" and the scientific community has reached a "*consensus*". Let us see what happened around 2000 and what is the situation today.

Before 2000 the general agreement among climate scientists was that the natural climatic variability during the last 1000 years could not be explained by the CO_2 records because the data were showing a large preindustrial variability with a quite warm Medieval Warm Period (900-1300) and a relatively cold Little Ice Age (1400-1800). On the contrary, the greenhouse gas records were showing a very modest variability. Solar variability, on the contrary, better fit and explained the observed large climatic variability (Eddy, 1976; Hoyt & Schatten, 1993). In any case, any changes in GHG atmospheric concentration before 1900 should be considered a natural feedback to climatic changes due to other forcings. This understanding was collected and acknowledged also in the first Climate Change IPCC Scientific Report published in 1990-1991.

However, in the third IPCC Assessment Report published in 2001, it was claimed that the pre-industrial climatic variability was significantly small. The novel north hemisphere temperature reconstruction depicted in Figure 8A was produced (Mann *et alii*, 1999; IPCC, 2001). It showed a nearly climatic stability from 1000 AD to 1900 AD with a variation of about 0.2°C (that is, the Medieval Warm Period was canceled), plus an abruptly and unprecedented warming from 1900 to 2000. Because of this peculiar shape, this temperature record was labeled the *Hockey Stick* temperature reconstruction. Simultaneously, the climate models available during that period were claimed to have been sufficiently validated because they were able to approximately reconstruct such a hockey stick pattern. These models showed a very modest climatic change from 1000 AD to 1900 AD followed by an abrupt warming from 1900 to 2000 induced by anthropogenic greenhouse forcing. For example, Crowley (2000) confirmed the validation of the available energy balance models by concluding: "*The very good agreement between models and data in the pre-anthropogenic interval also enhances confidence in the overall ability of climate models to simulate temperature variability on the largest scales*".

The hockey stick temperature pattern is perfectly consistent with that observed in Figure 1A where natural forcing alone is shown to produce only a very modest climatic variability. Indeed, this circumstance was very favorable to AGWT because it was taken for granted that the climate models supporting it had been validated (cf: IPCC, 2001, 2.3.4, p. 136).

However, McIntyre & McKitrick (2003) soon found severe errors in the hockey stick temperature record by Mann *et alii* (1999) and since 2005 alternative reconstructions of the Northern Hemisphere temperature have been proposed (Moberg *et alii*, 2005; Mann *et alii*, 2008; Ljungqvist, 2010; Christiansen & Ljungqvist, 2012). Figure 8B shows one of these new North Hemisphere temperature reconstructions (Ljungqvist, 2010). Consequently, the science surrounding the hockey stick temperature graph has been labeled an *illusion* (Montford, 2010).

The new available global surface temperature reconstructions demonstrated that the climate has been characterized by a large millennial oscillation during the last 2000 years. For example, the cooling observed from the Medieval Warm Period (about 1000 AD) to the Little Ice Age (1700 AD) is at least 3-4 times larger (about 0.7°C) than that shown in the hockey stick temperature reconstructions (about 0.2°C). Thus, these new paleoclimate temperature reconstructions confirmed the paleoclimatic studies published before 2000 while contradicting the hockey stick temperature reconstructions.

A direct and evident implication of these new paleoclimatic reconstructions of the last 1000 years was the rebuttal of claims such as those by Crowley (2000), which reopened the issue regarding the validation of the climate models. The main issue is: are these climate models able to reconstruct the Medieval Warm Period?

Figure 9 compares an ensemble of recent reconstructions of the climate of the past 1000 years (gray areas) against the last millennium climate model ensemble simulations using strong (red) or weak (blue) solar variability forcing reported in the IPCC (2013). The computer model simulations fail to reconstruct the Medieval Warm Period suggesting that these computer models miss the very climatic mechanisms that could explain such natural warm periods. This result is significant because the warming observed since 1900 started in reality in the early 18th century, that is, since the end of the Little Ice Age. This happened well before the anthropogenic GHG emissions could have had any significant impact on the climate. Thus, the modern warming period could also be the result of a natural warming trend due to a quasi millennial oscillation that both climate and solar records manifest quite clearly throughout the Holocene, but these models do not reproduce.

Scafetta (2013a) showed that the large climatic variability observed since the medieval times can be correctly interpreted only if the climatic effects of solar variability on the climate have been severely underestimated by the climate models by a 3 to 6 factor and simultaneously the climatic effect of the radiative forcings, which include the CO_2 forcing, has been overestimated by at least a factor of 2 by the same models. Therefore, either the total solar irradiance varied much more than what the solar forcing function used by the models show, or additional solar/astronomical related forcings are missing, or both.

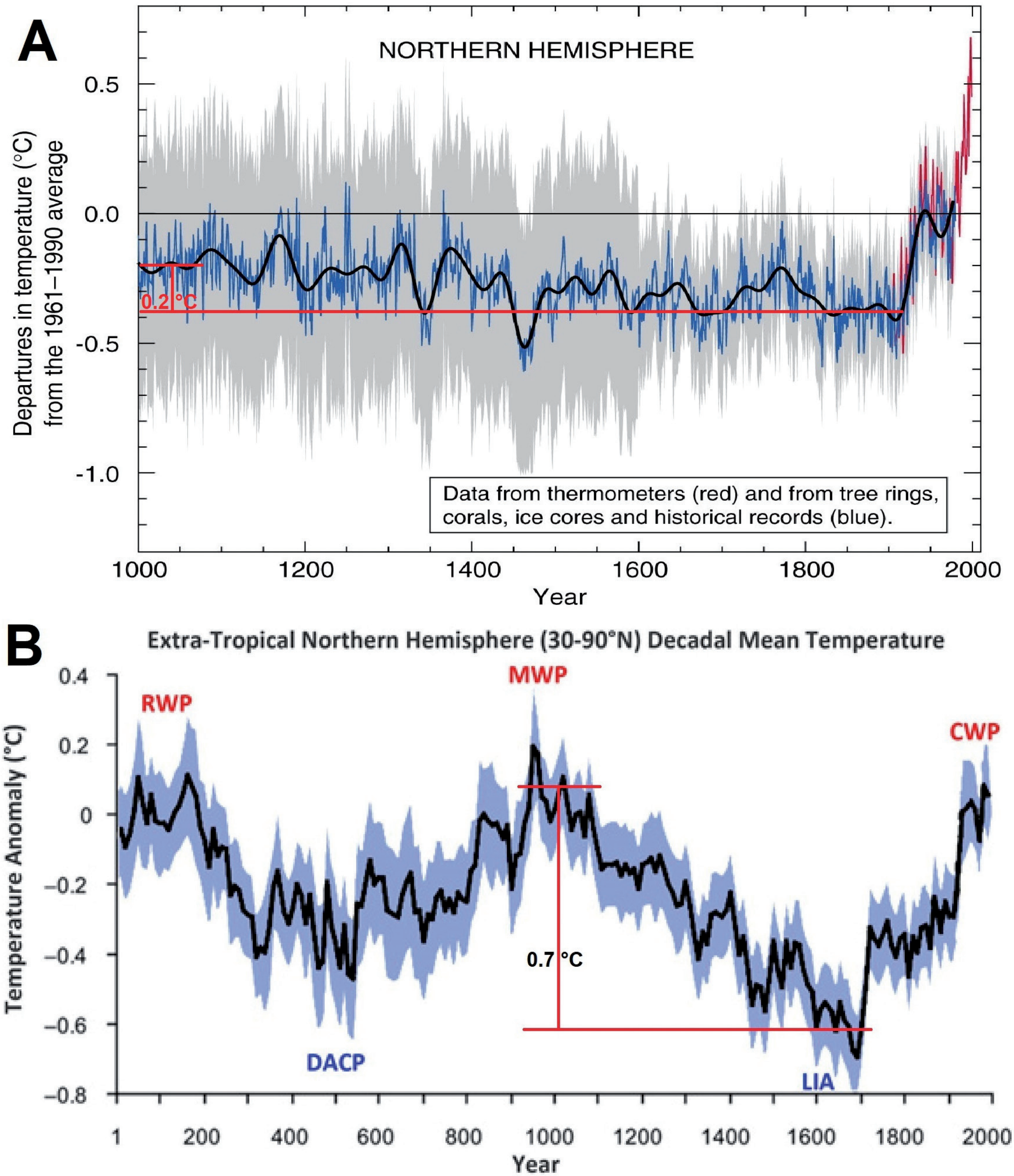

Fig. 8 - Comparison between [A] the Hockey Stick temperature reconstruction developed around 2000 (Mann et alii, 1999) and [B] a recent temperature reconstruction of the Northern Hemisphere showing a much larger natural variability (Ljungqvist, 2010). Note the different amplitudes of the cooling (0.2°C versus 0.7°C) between the Medieval Warm Period (MWP) and the Litle Ice Age (LIA)

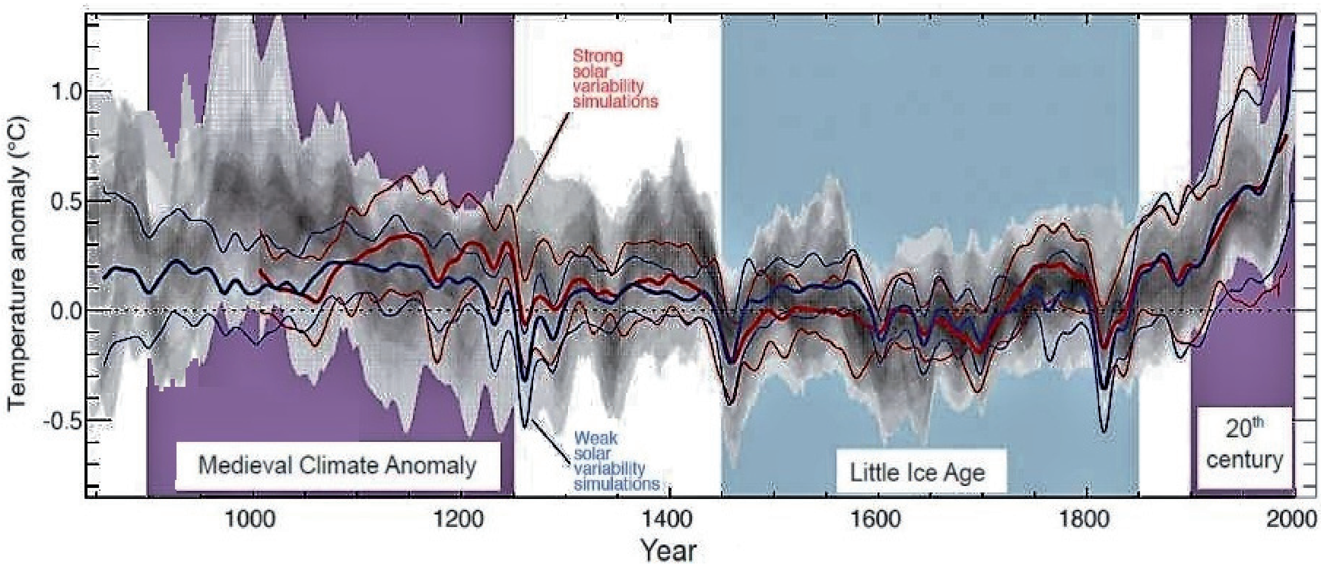

Fig. 9 - Comparison between recent reconstructions of the North Hemisphere temperature reconstruction (gray) and the last millennium climate model simulations (red and blue) (IPCC, 2013, available also at https://www.ncdc.noaa.gov/global-warming/last-1000-years). Note the failure of the models in reconstructing the Medieval Warm Period around 1000 AD

From 1850 to 2015

Evaluating the ability of the general circulation models to properly reconstruct the climate patterns observed from 1850 to the present is far more complex because the main pattern is just the observed secular warming of about 0.9°C. Typically proposed graphs are similar to Figure 1B that gives an impression of a good agreement between data and models.

However, this good agreement could be accidental because a simple warming trend could be reproduced in many alternative ways. As discussed previously, the failure of the models to reconstruct the warming periods of the last millennia suggests that they miss the very mechanisms able to reproduce such warm periods, which do not look particularly different or cooler than the current one. Those warm periods even repeated every about 1000 years so that a warm period during the 20th and 21st century could have been expected. On the other side, the large ECS uncertainty makes possible to adjust the internal parameters of the models to overestimate their ECS so that they could appear to reproduce correctly the warming since the pre-industrial time by simply taking advantage of the fact that anthropogenic greenhouse emissions have increased since then. Thus, without looking at the previous centuries and millennia, it would be quite difficult to validate or test these models using just the data from 1850 to present. At the moment, any test needs to focus on shorter time scales where the magnitude of the observed patterns is small and, therefore, it is also more difficult to analyze or recognize them.

Regarding a possible statistical divergence between data and simulated climatic trends, in 2009 AGWT advocates acknowledged that: "*Near-zero and even negative trends are common for intervals of a decade or less in the simulations, due to the model's internal climate variability. The simulations rule out (at the 95% level) zero trends for intervals of 15 years or more, suggesting that an observed absence of warming of this duration is needed to create a discrepancy with the expected present-day warming rate*" (Knight *et alii*, 2009). Meehl *et alii* (2011) showed that GCMs could simulate hiatus periods by occasional deep-ocean heat uptake, by simulating, at random times, an up-to-a-decade of steady temperature despite an increasing anthropogenic forcing. Thus, according to the AGWT advocates own criteria, a divergence between observations and climate models occurring at the decadal time scale and above would provide strong convincing evidence that the GCMs used to support the AGWT are severely flawed. This criterion rules out tests based on shorter sub-decadal time scales such as those referring to El-Nino fluctuations that these models are not supposed to reproduce. Therefore, there is a need to focus on the decadal and multidecadal scales and test whether the climate models properly reconstruct climate changes at these scales.

By looking carefully at Figure 1B, the data appear to be characterized by a large oscillation with a period of about 60 years that the models do not reproduce. In fact, the following patterns are most evident in the temperature data: the 30-year periods 1850-1880, 1919-1940 and 1970-2000 were characterized by an evident warming; the periods 1980-1910, 1940-1970 were characterized by an evident cooling; since 2000 the global surface temperature has been nearly stationary even though the 2015-2016 has been particularly warmer than the previous

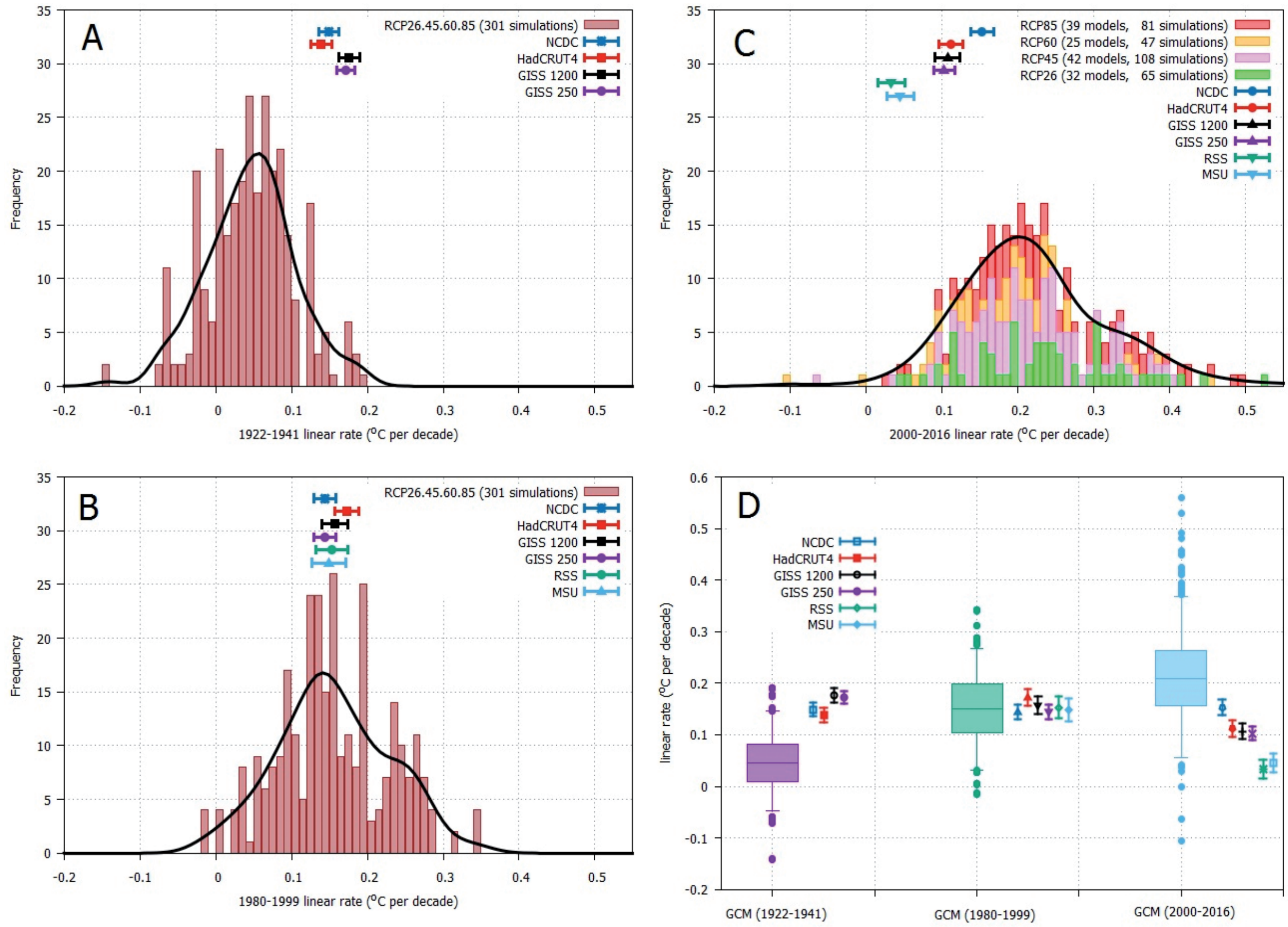

Fig. 10 - [A, B, C] Distribution of the linear rate trends of the 301 GCM individual simulations versus the six temperature records in the three-time intervals Jan/1922-Dec/1941, Jan/1980-Dec/1999, and Jan/2000-Dec/2016. [D] Percentile diagrams of the same: the statistical intervals of the boxplots are 5%, 25%, 50%, 75%, and 95%. Note the severe data-model divergence during the 1922-1941 and 2000-2016 periods

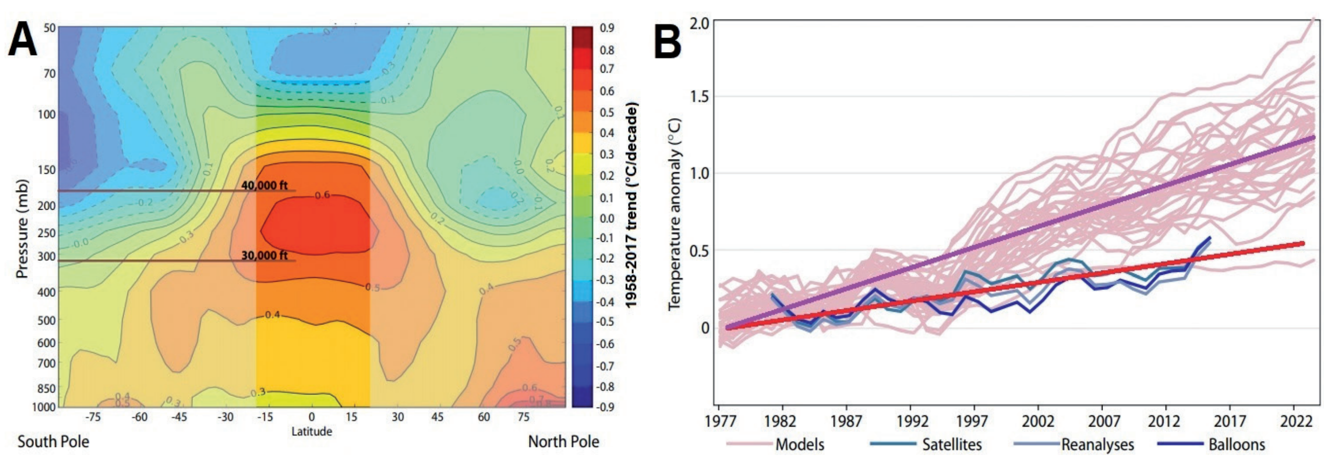

Fig. 11 - [A] Warming trend pattern in the troposphere predicted in a Canadian climate model from 1958 to 2017. The horizontal axis shows latitude, the vertical axis shows altitude, and color shows warming trend magnitude. [B] Tropical mid-tropospheric temperature models (pink) against various observational datasets (shades of blue). Adapted from McKitrick & Christy (2018). Note the data-model divergence in the temperature trend with the significant overestimation of the models

years because of a strong El-Nino warming event (Scafetta *et alii*, 2017b). The presence of this large 60-year modulation in the climate system has been confirmed by a very large number of works (Scafetta, 2010; 2012a; 2012b; 2013a; 2013b; 2014; 2016; Gervais, 2016; Wyatt & Curry, 2014; their citations and many others). In fact, a quasi 60 year oscillation has been found in several records, some of them several centuries and even millennia long, such as global and regional temperature records, in rainfall records, in sea level records, in proxy climate records of the Atlantic Multidecadal Oscillation, of the Pacific Decadal Oscillation, of the North Atlantic Oscillation, in various ice core, tree ring and sediment climatic proxy records and in many others.

Figure 1B shows that the models underestimate the warming observed from 1910-1940 (when very little anthropogenic forcing existed) and overestimate that observed after 2000 (when very strong anthropogenic forcing existed). This situation was tested for example in Scafetta *et alii* (2017a) where the warming trends of several hundred CMIP5 simulations were compared against that of six temperature records in the 20-year time intervals 1922-1941, 1980-1999 and 2000-2016 (the latter period was analyzed after the El-Nino signal was removed from the data to avoid a statistical bias since these climate models are not supposed to reproduce such fast and strong climatic oscillations). The histogram results are shown in Figure 10 where the discrepancy between the models and data in 1922-1941 and 2000-2016 is evident with statistical confidence larger than 95%. This result suggests that the good agreement observed in 1980-1999 is coincidental and likely due to a careful calibration of the internal parameters of the models.

The models' failure of correctly reconstructing the nearly stationary temperature trend after 2000 is proved also by the tropospheric temperature records. Infact, for the last decades, climate models predict a hot-spot, that is, a magnified warming of the upper troposphere at about 10 km over the tropics and the equator (see Fig. 11A). The presence of this hot-spot is quite important because it would indicate that the water vapor feedback to radiative forcing is correctly modeled. However, tropospheric temperature records do not show this strong warming (Douglass *et alii*, 2007; Christy *et alii*, 2010) suggesting either that the temperature records obtained with satellite measures and balloons is misleading (which is unlikely) or that the climate models macroscopically fail to properly simulate the water-vapor feedback and, therefore, mistake the modeling of the greenhouse effect by overestimating it. In the latter case, the models' flaws would be fatal because the water-vapor feedback is the most important among the climate feedbacks and without it, the models would only predict a moderate ECS to radiative forcing of about 1.0°C for CO_2 doubling instead of about 3°C, as on average the CMIP5 GCMs predict. Figure 11B compares the observed temperature trend in the troposphere versus the CMIP5 climate model predictions published in a recent work by McKitrick & Christy (2018). The variance between the simulated and recorded temperature trends is evident, and the authors conclude that "*this provides informative evidence against the major hypothesis in most current climate models*". Thus, also this result argues against the reliability of the GCMs, which are proven again and again to overestimate the climatic warming that an increase of atmospheric CO_2 concentration could cause.

Technically, ensemble mean model simulation graphs, where the simulations of all models are plot together in a temperature anomaly scale like in Figure 1 must not be interpreted as the output of a kind of super climate model, because it is just a statistical construction that can more easily hide the flaws of the single GCMs. It may be possible that one model reconstructs better a specific period and another model reconstructs better another period. When the simulations of the two models are plotted together on the same graph using the same color for the curves, it gives the impression that this overlapped image superimposes better with the data and, therefore, that the models reconstruct the temperature record but, in reality, they do not.

The discrepancy between data and models appears more evident when the data are compared against the simulations produced by every single model. Scafetta (2013a) showed such a direct comparison relative to 48 alternative CMIP5 GCMs, and each of them was shown to perform quite poorly in properly reconstructing climate change patterns from 1860 to date. In that occasion it was shown that the global surface temperature records (e.g. the HadCRUT, Morice *et alii*, 2012) are characterized by a warming secular trend (which can be approximately captured by a parabolic curve) plus a set of major oscillations with periods of about 9.1, 10.4, 20, and 60 years. The quasi-steady temperature trend from 2000 to date is one of the effects of these oscillations, which are present for the entire period from 1860 to date. Statistical analysis of these oscillations concluded that none of the CMIP3 and CMIP5 climate models can model them since 1850 (Scafetta, 2012a; 2013a). Figure 12 shows such an analysis that tests the ability of each of the 162 available CMIP5 climate simulations produced by 48 different models in reconstructing the four observed oscillations (at 9.1, 10.4, 20, and 60 years) and the upward temperature warming since 1860. The figure shows the relative regression coefficient, which means that the yellow area around the value of 1 represents the pattern observed in the data within a 1-σ uncertainty, while the red dots are the equivalent values deduced by the models. More they diverge from 1 more poorly they reproduce the correspondent oscillation or trend. The figure clearly shows the poor performance of these climate simulations, in particular in reproducing the 60-year oscillation, which is fatal for the validation of these GCMs because they are supposed to properly reproduce climate change at the decadal scale and above.

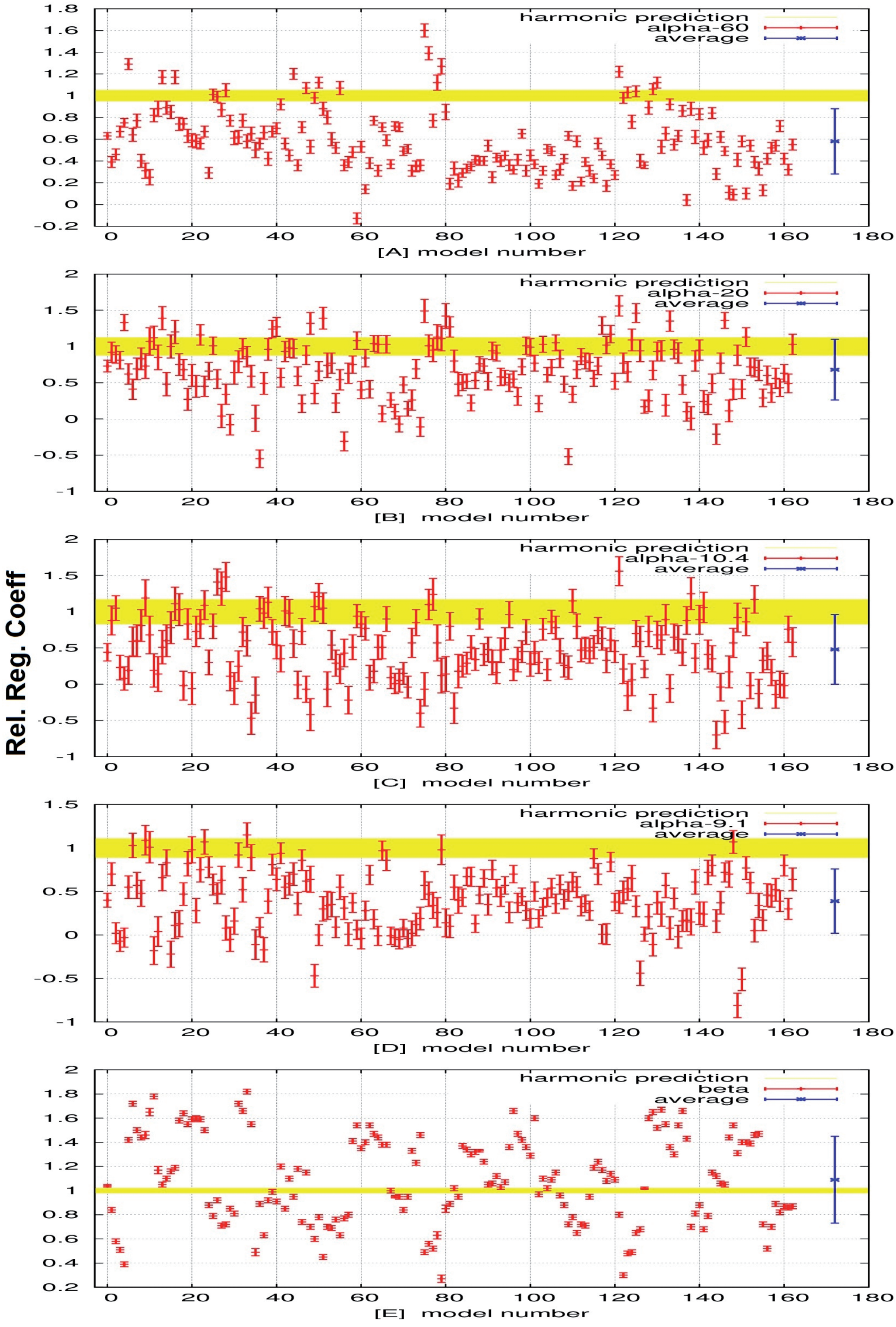

Fig. 12 - Multiple tests to determine the ability of the CMIP5 GCMs' simulations in reproducing the observed climatic oscillation at 9.1, 10.4, 20 and 60 year period plus the quadratic upward trend from 1860 to 2012. The yellow area around the value of 1 corresponds to the observations within 1-σ error, the red dots are results from the models. The blue bars are the ensemble values with relative error bars regarding the models

This failure in properly reconstructing the observed climatic variability from 1850 to date at multiple decadal and multidecadal scales persists also in the new generation CMIP6 models. For example, Figure 13 shows several global surface temperature records against the ensemble simulations of the DOE E3SM coupled GCM version 1 (Golaz *et alii*, 2019). The divergence between the data and the model after 1950 is macroscopic. In particular, the volcano cooling is exaggerated and since 2000 this model predicts a warming rate of about 0.4°C/decade, which is about 4 times larger than what the data show (cf. Figure 10). Golaz *et alii* (2019) attributed this divergence to the model's too strong aerosol-related effective radiative forcing and a too high equilibrium climate sensitivity to radiative forcing. Thus, it appears again evident that the models fail to reproduce the natural climatic variability and try to get the observed warming from 1850 to date with anthropogenic forcing and high ECS.

A final issue regards how well the CMIP5 GCMs reconstruct the mean absolute temperature of the Earth. Previous figures only plot the GCM simulations in the temperature anomaly scale, that is, relative to a given mean during a certain period, for example, 1961-1990 or another. During the 20th century, the average temperature of the Earth was about 14-15°C. Figure 14 compares two global surface temperature records in the absolute scales from NCDC and Berkeley BEST (available at Climate Explorer) against all CMIP5 simulations. The figure shows that in the absolute scale the computer simulations provide very different mean temperatures: some models show mean values of about 12-13°C while others show mean values of 15-16°C. This result appears quite unsatisfactory because an error of 3°C in the absolute temperature is a too large uncertainty for correctly interpreting the observed climatic changes.

Many other cases can be discussed and they may focus on local, rather than global climates. For example, Scafetta & Mazzarella (2015) studied the Arctic and Antarctic sea-ice area extension records versus measured and modeled temperature data since 1980. It was demonstrated that while the Arctic has been warming approximately as predicted by the climate models, the Antarctic sea region has been cooling. The cooling trend observed around Antarctica significantly contradicts the warming predicted by the CMIP5 GCMs during the same period and over the same region. Figure 15 shows another important local case study by comparing the number of Atlantic Hurricanes observed and estimated from 1878 to 2015 (Vecchi & Knutson, 2011) and the Atlantic Multidecadal Oscillation, which is the linearly detrended Atlantic sea surface temperature between the equator and Greenland. These records clearly show a very strong correlated 60-year cycle from 1878 to 2015. However, it poorly correlates with the increasing trend of the anthropogenic emissions shown in Figure 3. The climate models do not reproduce this 60-year oscillation observed in many regions of the Earth.

All the above pieces of evidence are sufficient to demonstrate that the climate system is more complex than what assumed by the current climate models adopted by the IPCC to support the AGWT. The solar effect appears significantly underestimated, and the effects of the radiative forcings appear significantly overestimated by at least a factor of two.

A SEMI-EMPIRICAL CLIMATE MODEL BASED ON NATURAL OSCILLATIONS

The evidences discussed above suggest that current climate models do not properly interpret climate change. The very large uncertainty in the ECS (Fig. 4) easily allows reconstructing the warming observed from 1850 to date also using flawed models. It appears as if the internal parameters of the models were chosen to compensate for the lack of knowledge in the physical processes regulating climate change and to simulate the warming observed since the pre-industrial times using the anthropogenic forcings. This operation yielded to climate models predicting too high ECS values. However, as soon as past warm periods, various climatic oscillations, regional comparisons, and other considerations are taken into account, the limits of these models appear evident. The evidence is that some internal physical mechanisms are missing or poorly modeled, which include cloud formation physics, ocean/atmospheric circulation dynamics and, in addition, some important climate forcing could also be missing. All this implies that the science of climate change is not sufficiently developed to produce reliable dynamical models such as the GCMs. Thus, empirical and semi-empirical climate models should be used to attempt to model climatic changes.

The existence of 20 and 60-year natural climatic oscillations implies that about 50% of the warming observed from 1970 to 2000 was very likely induced by them (e.g.: Scafetta, 2010; 2013a). The same conclusion is derived from an analysis of the novel proxy climate records available since medieval times. This leaves only the leftover 50% warming of the 20th century to anthropogenic forcings, not nearly 100% as claimed by the CMIP5 GCMs. Thus, the real ECS seems to be at least half than what the CMIP5 models predict, that is, around 1.5°C instead of 3°C.

What could the missing climate components be? As explained above, there are strong empirical pieces of evidence that the missing mechanisms have to do with solar activity or with those astronomical phenomena that could be regulating solar activity. During the Medieval Warm Period (c. 900-1300), solar activity was high and the climate was warm, during the Little Ice Age (c. 1400-1800) solar activity was generally low, such as during the Maunder (1645-1715) or Dalton (1790-1830) grand solar minima, and the temperature was low (Eddy, 1976). From the Dalton minimum solar activity increased up to the late 20th century and empirical studies suggest that it may have induced at least 50% of the observed warming (Scafetta & West, 2006; Scafetta, 2009; 2011). This is

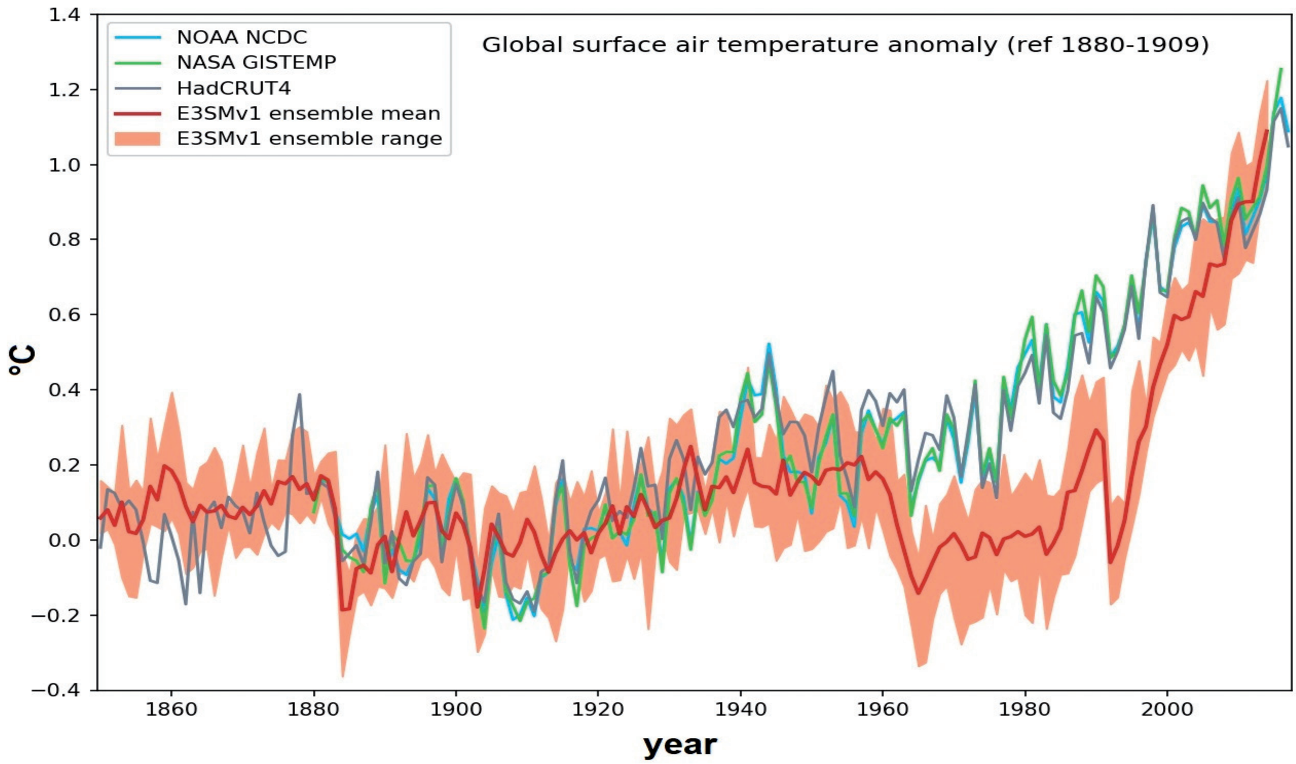

Fig. 13 - Comparison between observations from NOAA NCDC (blue), NASA GISTEMP (green), HadCRUT4 (grey) and E3SMv1 ensemble mean and range (red and orange) (source: Golaz et alii, 2019). Note the large data-model divergence after 1950

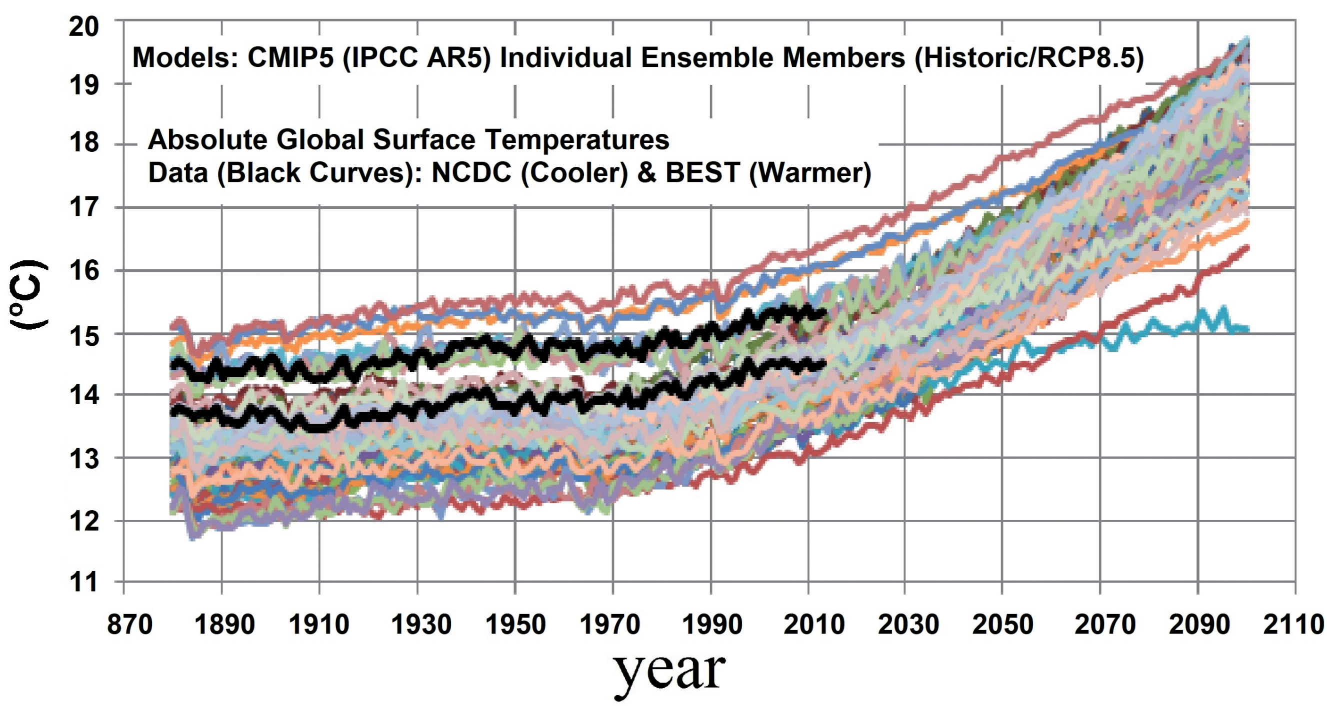

Fig. 14 - Comparison between global surface temperature records and CMIP5 GCMs' simulations in the absolute temperature scale

shown in Figure 16 that compares a reconstruction of global surface temperature change from 1600 to 2010 against empirical reconstructions of the climatic signature of possible solar variations.

A careful analysis of the gravitational oscillations of the solar system and the solar-lunar tidal system has shown that astronomical and climate records share a large number of harmonics (e.g.: Scafetta, 2010; 2012a; 2012b; 2013a; 2013b; 2016; 2018). The solar system is characterized by a set of specific gravitational oscillations since the planets are moving around the sun. Everything in the solar system, including the sun itself, tends to synchronize to these frequencies. Then, the oscillating sun and the heliosphere could induce equivalent cycles in the climate system because it must synchronize with its external harmonic forcings. Besides, also the sun/moon system has to act on the climate with its tidal harmonics. In conclusion, we should expect a climate system that is mostly modulated by a set of complex cycles that mirror the astronomical ones. It is possible to use these same harmonics, which can be derived directly from astronomy, to hindcast and forecast the harmonic component of the climate, at least on a global scale. This theory is indeed supported by strong empirical evidences using the available solar and climatic data.

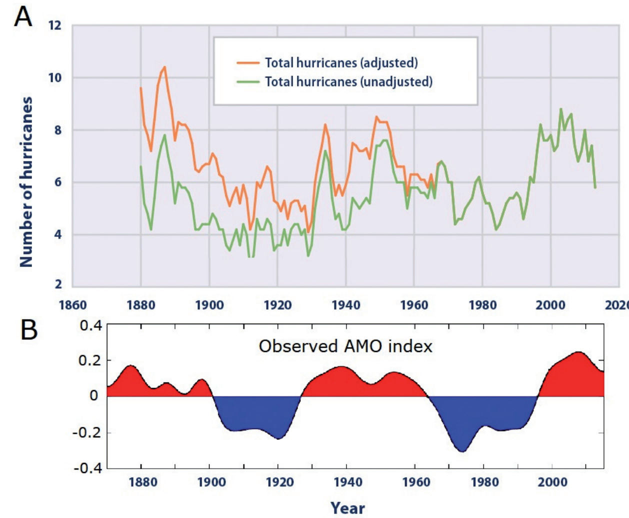

Fig. 15 - [A] Number of hurricanes that formed in the North Atlantic Ocean each year from 1878 to 2015. The orange curve shows how the total count in the green curve can be adjusted to attempt to account for the lack of aircraft and satellite observations in the early years (Vecchi & Knutson, 2011). [B] Atlantic multidecadal oscillation. Note the common 60-year oscillation

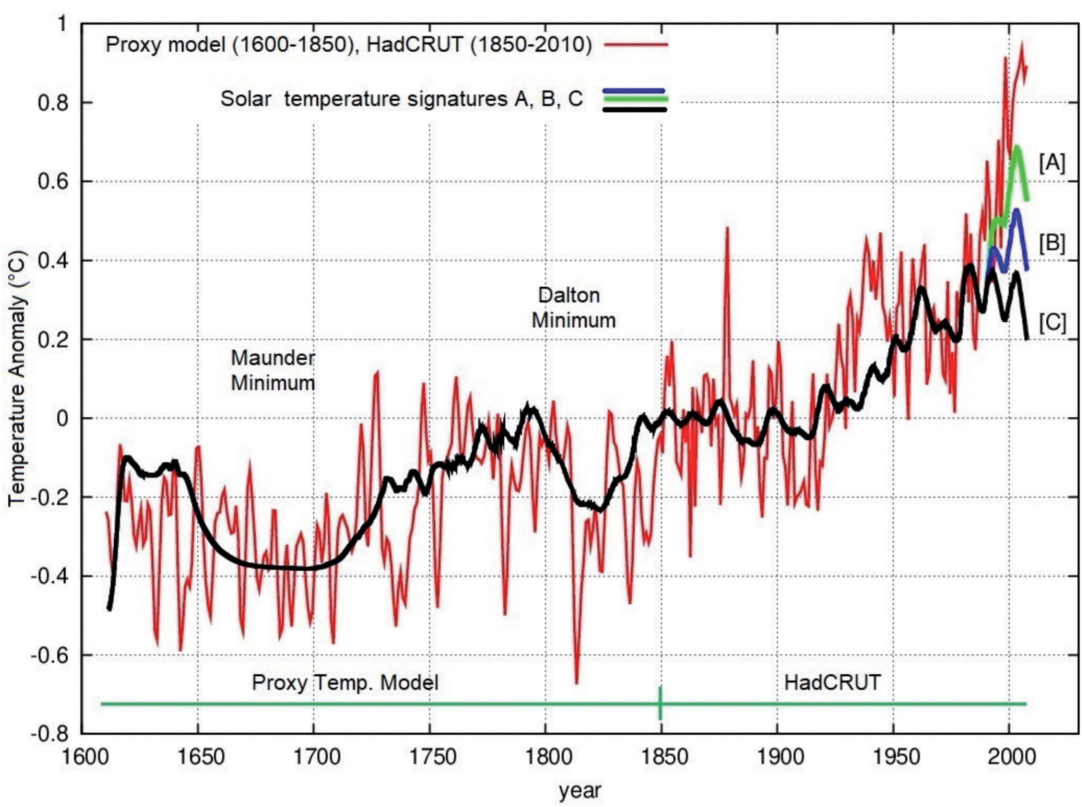

Fig. 16 - An estimate of the global surface temperature from 1600 to 2010 using the global proxy temperature model by Moberg et alii (2005) merged with the HadCRUT instrumental global surface temperature record from 1850 to 2010. The other curves are three possible climatic signatures of the solar variability (Scafetta & West, 2006; Scafetta, 2009; 2011). Note that on average nearly half of the observed warming since 1900 could be due to the sun

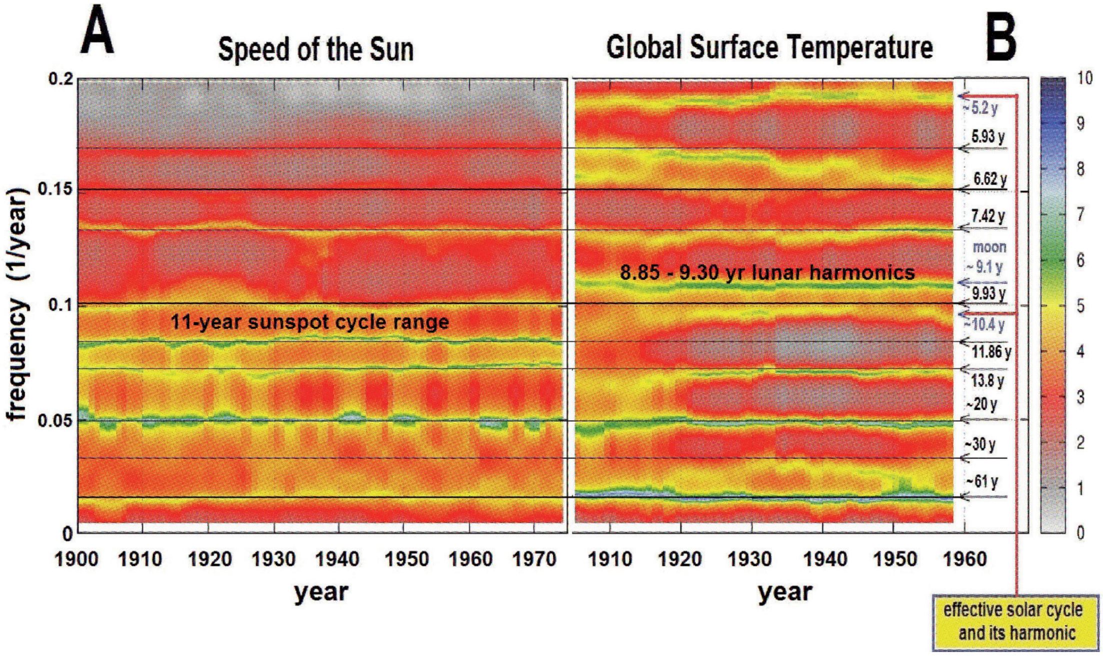

Fig. 17 - Comparison between the continuous spectral analysis of the speed of the sun relative to the barycentre of the solar system (left) and the global surface temperature record (right). (Source: Scafetta, 2013a)

Figure 17 depicts a comparison between the continuous spectral analysis of the speed of the sun relative to the barycentre of the solar system - which is a good proxy for determining the major gravitational oscillation of the solar system - and of the global surface temperature records (Scafetta, 2013a). High resolution continuous spectral methodologies have further shown that the spectral coherence between the two records has statistical confidence of 95% for the oscillations with the following periods: 6.6, 7.4, 14, 20 and 60 years (Scafetta, 2016; 2018). Figure 17 also shows that the temperature is characterized by a quasi 9.1-year oscillation which is not present in the analyzed solar record. However, this oscillation is clearly a solar-lunar tidal oscillation because this period falls within three lunar cycles: (1) the 8.85 lunar perigee cycle; (2) the second harmonic of the 18-year Saros eclipse cycle (about 9 years); (3) the second harmonic of the 18.6 lunar nodal cycle (about 9.3 years) (Scafetta, 2012a; Haigh *et alii*, 2011). In addition, the varying temperature oscillation observed between the 10 and 12-year astronomical periods is its signature of the sun-spot cycle record. The 11-year solar cycle is bounded by the 9.93-year Jupiter-Saturn spring tidal cycle and the 11.86-year Jupiter orbital tidal cycle (Scafetta, 2012c), and its length has slightly decreased from 1850 to 2000. Scafetta (2012c) also demonstrates that the combination of the above two planetary tidal oscillations and the 11-year solar cycle produces beats with a period of about 115 and 983 years. These long oscillations are synchronous with equivalent oscillations observed in the climate and solar records during the Holocene and especially during the last 2000 years. Note that a combination of the tidal function generated by Venus, Earth and Jupiter synchronizes the 11-year sun spot cycle (cf. Scafetta, 2012c), a fact recently confirmed also by Stefani *et alii* (2019).

Scafetta (2010; 2013a) has also proposed that the global surface temperature record could be reconstructed from the decadal to the millennial scale using a minimum of 6 harmonics at 9.1, 10.4, 20, 60, 115 and 983 years plus an anthropogenic and volcano contribution that could be evaluated from the CMIP5 GCM simulation outputs but reduced by half their predicted signature. As discussed above, the real climate sensitivity to radiative forcing should be about half of what assumed by the current GCMs. Figures 18 and 19 highlight the superior performance of the solar-astronomical semi-empirical model versus the CMIP5 models in reconstructing two alternative temperature records: HadCRUT4 global surface temperature record (Morice *et alii*, 2012) and UAH-MSU global lower tropospheric temperature record (Christy *et alii*, 2007). The better performance of Scafetta's 2013a model is particularly evident since 2000. The 2015-2016 warm peak was due to a strong El-Nino event, which is unrelated to anthropogenic activity. The semi-empirical model predicts for the future very moderate warming until 2030-2040 up to a theoretical maximum of 2.5°C for 2100 relative to pre-industrial times (1850-1900) according to the RCP 8.5 scenario. Thus, future climatic changes derived from this modeling will occur slowly. They will be modest and significantly less alarming than those associated with the 5°C warming predicted by the CMIP5 models.

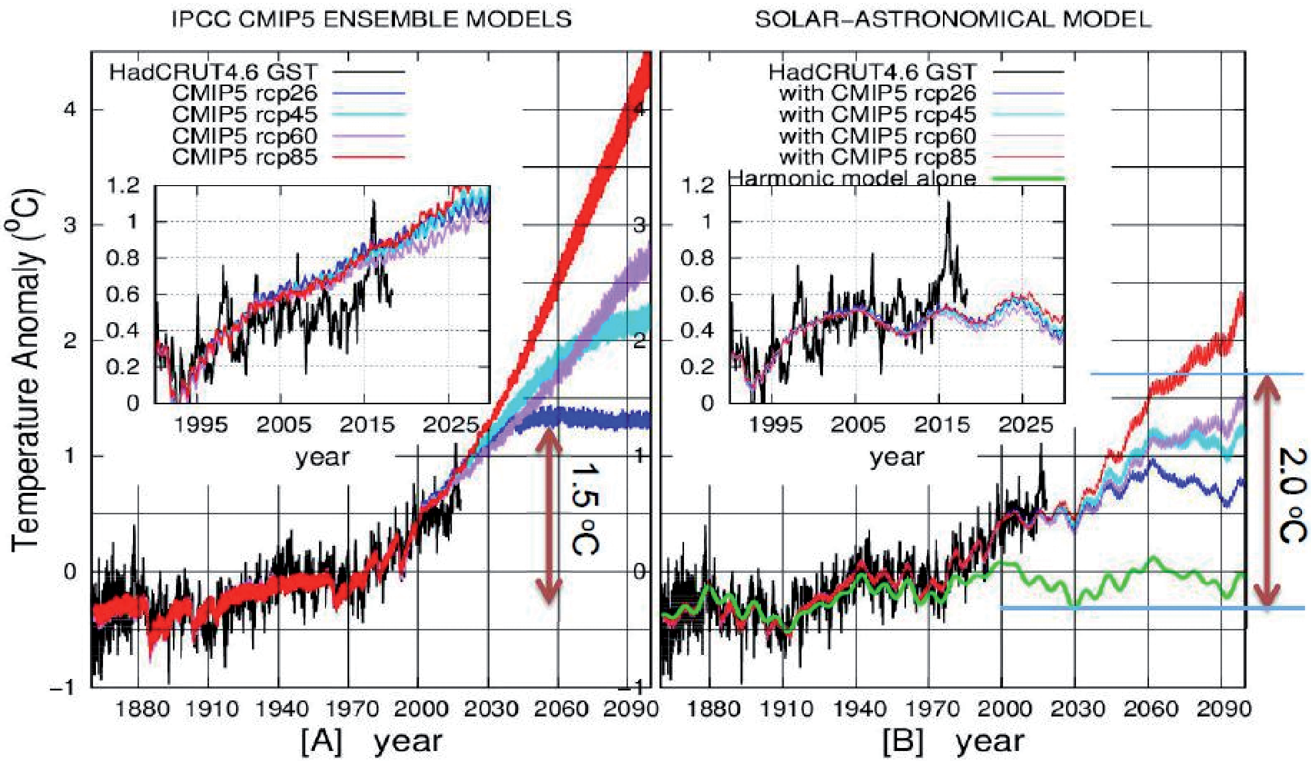

Fig. 18 - [A] The four CMIP5 ensemble average projections versus the HadCRUT4 GST record (black). [B] The solar–astronomical semi-empirical model. Updated from Scafetta *(2013a)*

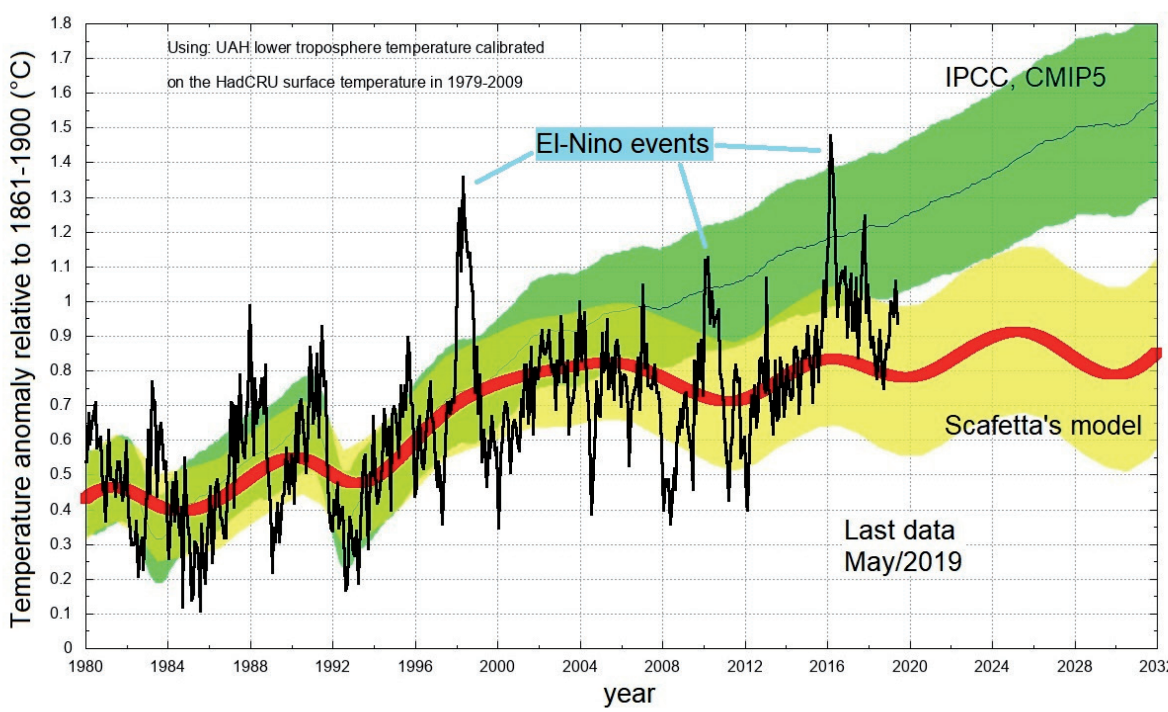

Fig. 19 - The global monthly average lower troposphere temperature since 1979 according to the University of Alabama at Huntsville (UAH), USA (black) up to May 2019 versus the CMIP5 ensemble average projections (green) versus the solar–astronomical semi-empirical model (yellow). The green and yellow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

CONCLUSION

Since 1850 the global surface temperature has warmed by about 0.9°C. This warming has been interpreted using climate models such as the CMIP5 GCMs. The conclusion deduced from their simulations was that the observed 20th-century warming was almost entirely induced by anthropogenic emissions produced by fossil fuel burning. The same computer climate models were then adopted to evaluate climate projections for the 21st century and concluded that the temperature would rise rapidly up to 5°C from the pre-industrial temperature level (1850-1900) to 2100. These projections are currently used to justify expensive mitigation policies with the hope of severely reducing GHG emissions and control climate change.

However, these computer climate models are only scientific hypotheses that require some kind of validation before their scientific conclusions could be trusted. Herein I have shown that recent scientific research points out that the IPCC climate models fail to properly reconstruct the natural variability of the climate at multiple time scales throughout the entire Holocene. Many climatic issues remain open, indeed.

For example, another important issue is to determine how much of the observed warming since 1900 has been induced by non climatic factors such as urbanization. In fact, while climate models associate the global and local warming to anthropogenic forcing, a new study finds that past temperature records have failed to accurately detect urbanisation biases, which may account for about 50% of the recorded warming in China since the 1940s (Scafetta & Ouyang, 2019). In addition, advanced techniques of pattern recognition have pointed out that the natural variability of the climate appears to be made not only of volcano sudden cooling spikes but also of several oscillations from the decadal to the multi-millennial scales (e.g. periods of about 9.1, 10.4, 20, 60, 115, 1000 years and others). Numerous pieces of evidence suggest that these oscillations have an astronomical origin. Other evidences for a planetary modulation of solar activity are proposed in Scafetta *et alii* (2016).

The considerations emerging from these findings yield to the conclusion that the IPCC climate models have severely overestimated the anthropogenic climatic warming by at least a factor of two.

I have finally proposed a semi-empirical climate model calibrated in such a way to reconstruct the natural climatic variability since medieval times because it includes the millennial oscillation observed throughout the Holocene (Scafetta 2013a; 2013b). I have shown that this model projects very moderate warming until 2040 and a maximum additional warming of about 1.5°C from 2000 to 2100 using the same anthropogenic emission scenarios adopted by the CMIP5 models: see Figures 18-19.

This result suggests that climatic adaptation policies, which are less expensive than the mitigation ones, could be sufficient to address most of the consequences of climatic changes that could occur during the 21st century. A major scientific implication of this research is that the climate is significantly modulated by astronomical oscillations which may generate solar-associated forcings different from the total solar irradiance forcing. This eventuality would further suggest that the current models are not reliable because important space weather climate forcings are still poorly understood and not included in the GCMs.

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Received February 2019 - Accepted May 2019

