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Reply to comment by J. L. Lean on "Estimated solar contribution to the global surface warming using the ACRIM TSI satellite composite"

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[1] We thank Lean and hope our reply clarifies any ambiguities in our original paper [*Scafetta and West*, 2005].

[2] *Lean* [2006] (hereinafter referred to as *Lean*) stresses that our finding (that the Sun contributed at least 10–30% of the 0.40 ± 0.04 *K* global surface warming) depends crucially on the adoption of ACRIM total solar irradiance (TSI) composite [*Willson and Mordvinov*, 2003], instead of PMOD TSI composite [*Fröhlich and Lean*, 1998]. We agree and clearly stated this fact in our paper. Also, we briefly discussed the difference between ACRIM and PMOD in the introduction, as well. Of course, if PMOD is used, because it lacks any upward trend between solar cycles 21–23, the solar contribution to the global warming would be negligible during such a period, under the mathematical hypotheses made in our paper. *Lean* infers that our finding is erroneous because ACRIM is, in her opinion, erroneous. Nevertheless, solving and/or addressing the ACRIM-PMOD controversy was not the purpose of our paper, particularly because there are no unequivocal criteria for choosing one data set over the other yet.

[3] *Lean* argues that a comparison between Figures 1 and 4 in our paper would not support our assumption that "the upward modulation during solar cycles 21–23 can be minimally interpreted as a 22-year cycle modulation." This argument is based on a misunderstanding of both Figures. Figure 1 of *Scafetta and West* [2005] shows that, by adopting ACRIM, the TSI average during solar cycle 22–23 is higher than the TSI average during solar cycle 21–22 by $\Delta I_{sun} \approx 0.45$ W/m^2. This is the important phenomenological property of ACRIM that warms the climate during solar cycle 22–23. What we say is that the average ACRIM modulation, indicated by the black curve in Figure 1, can be interpreted as a modulation having a period of approximately 22 years or larger, being the case when two adjacent 11-year averages, which are not equal, are taken. In other words, this average TSI modulation is not a 10 or 5 years period modulation, as is evident by construction. Regarding Figure 4 *Lean* states that this figure shows a minimum close to 1991 for the 22-year modulation. However, that minimum occurs in 1987, and during 1991 the curve is increasing as it should. In fact, the $D_8(t)$ curve modulation shown in our Figure 4 is obtained after a detrending of the $S_8(t)$ secular smooth component of the signal as defined by the wavelet decomposition there adopted. Most of the jump occurring in 1991 in our Figure 1 is absorbed by this detrended secular smooth component.

[4] *Lean* adopts a multivariate linear regression analysis (MLRA) (which hypothesizes four separate signals: volcano, ENSO, CO_2 greenhouse gas plus tropospheric aerosol, and ACRIM), and shows that the ACRIM contribution to the warming is lower than we found. This is not surprising as *Scafetta and West* [2005] explained, even if briefly, that by using MLRA the ACRIM contribution to the warming would be underestimated for two major reasons.

[5] **Reason 1: Climate is not a Linear System**. *Lean*'s MLRA assumes that the temperature is a simple linear superposition of radiative forcings, while our own findings [*Scafetta and West*, 2005], the findings of *White et al.* [1997], and of *Wigley* [1988] establish that the climate sensitivity to radiative forcing is frequency-dependent and is stronger at lower than at higher frequencies; compare also Figures 1a and 1b in *Foukal et al.* [2004]. To explain this effect, Figure 1 herein shows the response of a hypothetical system with a given thermodynamical relaxation factor (for example, associated with the heat capacity of the system) to two external square waveform input signals with equal amplitude but different frequencies. The output signal amplitude and, therefore, the sensitivity of the system, is evidently larger at the lower frequency because the system has more time to relax to the input signal. *Lean*'s MLRA does not include this sensitivity-frequency effect and underestimates the climate sensitivity to the ACRIM secular solar increase. This is evident in the following example. Figure 2 herein shows the output response $T(t)$ of a hypothetical climate system to a hypothetical input TSI forcing $I(t)$ made with a cyclical component plus a lower frequency upward component, which mimics ACRIM. The system response is frequency-dependent and damps the higher frequency component of the input signal by 66% (as Table 1 in *Wigley* [1988] and a comparison between Figures 1a and 1b in *Foukal et al.* [2004] show for climate systems). The input TSI signal, through the frequency-dependent nonlinear response of the system, induces a warming equal to 2 generic units within the time interval shown in the figure. Instead, if we adopt MLRA we have to build a linear constructor function of the type $C(t) = \lambda I(t) + at + b$, where λ is a constant linear system sensitivity to the input signal $I(t)$ and $at + b$ is an additional linear component, which in

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Lean's interpretation would represent the anthropogenic component to the warming. MLRA calculates the best values of the three linear parameters to fit the output response $T(t)$ with the constructor $C(t)$ and finds $\lambda = 0.65$, $a = 0.41$ and $b = -0.41$. Although, as Figure 2 shows, $C(t)$ well fits $T(t)$, the physical interpretation is severely misleading because MLRA mistakenly finds that an additional linear-anthropogenic component would have contributed 41% of the warming, as measured by the parameter a, while by construction the warming of $T(t)$ is entirely induced by the input signal $I(t)$ through a frequency-dependent response of the system. In addition, MLRA is also lag-time sensitive and if the constructor function is not in the right phase there would be an additional error. For example, by assuming only a 10% time-lag error, $C(t) = \lambda I(t - 0.1) + at + b$, MLRA finds $\lambda = 0.56$, $a = 0.69$ and $b = -0.64$, and the conclusion would be that the non-existent linear-anthropogenic component would have contributed 69% of the warming! This example illustrates that MLRA can suggest severely misleading physical conclusions if it is applied to a system that has a frequency dependent response to the input forcing, as climate systems indeed do.

[6] **Reason 2: Climate Has Feedbacks to TSI Variations**. *Lean* assumes that the CO_2 greenhouse gas (GHG) plus aerosol concentration contribution to the warming is the *anthropogenic* contribution to the warming and uses MLRA to separate it, together with the ENSO signal, from the ACRIM contribution to the warming. We believe that Lean's reasoning is misleading. In fact if, according to ACRIM, TSI increased during solar cycles 21–23, such an increase, and the warming induced by it, could change the chemistry of the atmosphere and cause an increase of GHG as well, even without human contributions. For example: a TSI increase might cause: 1) more evaporation and, therefore, higher H_2O in the air (note that water vapor is by far the most powerful and important GHG whose contribution is ignored in *Lean*'s MLRA); 2) warmer oceans might reduce their CO_2 uptake and leave more CO_2 in the atmosphere [*Cox et al.*, 2000], and warmer climate might increase CO_2 production from bacteria [*Brandefelt and Holmén*, 2001]. Thus, if ACRIM is used, associating all CO_2 increase to human activity would be misleading because part of it could be indirectly induced by the TSI increase itself and this part should be considered a component of the solar contribution to climate change because it is a climate feedback to TSI variation. Lean, instead, includes in the anthropogenic contribution also the CO_2 increase induced by the TSI increase. Similar reasoning can be repeated for the ENSO signal that *Lean* removes from the data neglecting that part of the sun-climate signal could be embedded in it as another climate feedback to TSI change. In other words, GHG climate components depend on TSI variation too, while MLRA assumes their *independence*.

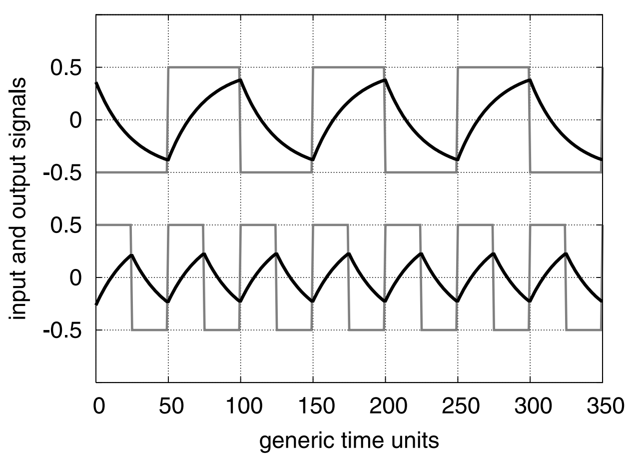

Figure 1. Responses (black curves) of a hypothetical system with a given thermodynamical relaxation factor ($f(t) \propto e^{t/\tau}$, $\tau = 25$) to two external square waveform input signals (gray curves) with equal amplitude but different frequencies. The response is stronger at lower frequency of the input signal.

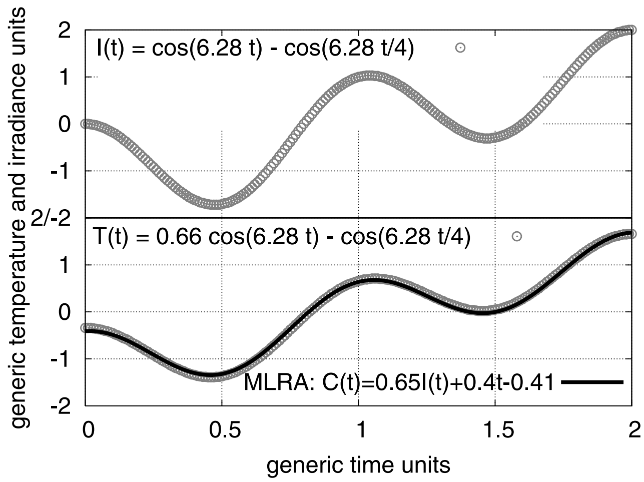

Figure 2. Response (output signal, $T(t)$) of a climate system to an external forcing (input signal, $I(t)$) through a nonlinear-frequency dependent sensitivity that damps the higher frequency component of $I(t)$. This frequency effect is qualitatively recovered by climate energy balance models [*Foukal et al.*, 2004, Figures 1a and 1b]. The curve $C(t)$ is the misleading MLRA constructor of $T(t)$.

[7] In conclusion, unless *Lean* takes into consideration the frequency-dependence of the climate sensitivity to radiative forcing, disentangles and then collects all direct and indirect solar effects on climate (including the CO_2 feedback component to TSI variation), which can be embedded in all climate components, MLRA is misleading and underestimates the sun-climate coupling. On the contrary, the *scale-by-scale transfer sensitivity analysis*, which works in the frequency domain, was adopted to circumvent the above problems.

[8] *Lean* uses MLRA with PMOD superimposed upon an upward *linear* secular irradiance trend of 0.047% per decade to argue that we are wrong in claiming that MLRA is not optimal for the analysis. We do not believe *Lean*'s reasoning is correct. First, it is not correct, as Lean states, that we assume ACRIM to have an upward *linear* secular irradiance trend. We assume ACRIM to have a step-like irradiance increase; this is stated in the paragraph including equation (1) of our paper, where ΔI_{sun} is defined. Second, the apparent agreement that *Lean* finds between her result and our finding is indeed due to the fact that on one side she adopts MLRA that significantly underestimates the contribution of a TSI increase to the warming (as we have

explained above) and, on the other side, she makes use of a upward *linear* secular TSI trend that overestimates such a contribution by about a factor of three; in fact, $2.2 \times 0.047\% \times 1366$ W/m^2 = 1.41 W/m^2 $\approx 3\Delta I_{sun}$. Thus, we believe that *Lean*'s result indeed derives from a calculation based on two erroneous physical assumptions that, accidentally, neutralize each other.

[9] In the last sentence of her comment *Lean* acknowledges that the temperature presents a 11-year solar-induced cycle with amplitude $A \approx 0.1$ K. Well, this is what we have found (see $A_{7,temp}$ given by *Scafetta and West* [2005]), and we think that this, even if indirectly, confirms our calculations.

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