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Climate
of the Past
Discussions

Interactive comment on "Influence of solar variability, CO_2 and orbital forcing during the last millennium in the IPSLCM4 model" *by* J. Servonnat et al.

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We thank both reviewers for their helpful corrections and constructive comments. Their original specific comments are preceded by "C# =>", and the responses are preceded by "R# =>". The responses to the technical comments are preceded by "=>" and follow directly the comments.

Anonymous Referee #1

The analysis presents a statistical approach to decompose the temperature response of a forced climate simulation into parts related to the applied forcings of the last millennium. The climate model IPSLCM4, which consists of an AOGCM coupled with a

sea-ice model and a vegetation model, is forced by greenhouse gas (GHG) concentrations and tropospheric aerosols in the control run (CTRL) and with variable Total Solar Irradiance (TSI), GHG concentrations and orbital parameters in the forced run (SGI). Although the results disclose no fundamental new findings, the work presents a careful interpretation of the simulation results including an evaluation of the simulated temperatures against proxy data reconstructions. The presentation of the results is well structured and the text well written. A new aspect is, that the analysis is done for continuously decreasing horizontal scales, i.e., from global to grid-cell scale. The finding of a significance threshold for the signal-to-noise ratio (SNR) to lie between 3-7 x 10ËĘ6 kmËĘ2 is an interesting conclusion.

Some specific comments and technical corrections are given for further improving the presentation.

Specific comments

C1 => The experimental design and Figure 1 describe two simulations (CTRL and SGI) from 1000 to 2000 AD. The statistical decomposition analysis seems to use only the simulated temperatures from the preindustrial period 1000 - 1850 AD. If that is the case then the title should be changed accordingly.

R1 => The title has been changed for "Influence of solar variability, CO2 and orbital forcing between 1000 and 1850 AD in the IPSLCM4 model"

C2 => The last sentence of the abstract (page 422 line 23-25) is difficult to understand. What is meant by individual temperature reconstructions? Do these temperatures show only a weak linear response to the external forcing because a) they show a non-linear response to the forcing, or b) they are affected by internal variability, or c) they are affected differently by the external forcings?

R2 => "Individual temperature reconstructions" meant "local temperature reconstructions". Concerning the second question, we wanted to say that the response to external forcings is weak compared to internal variability. We have replaced the last sentence of the abstract by "This study suggests that regional reconstructions of the temperature between 1000 and 1850 AD are likely to show weak signatures of solar, CO2 and orbital forcings compared to internal variability."

C3 => After a 110-year spin up of the model, a steady state is reached (page 427 line 5-6), but then the first 100 years of CTRL are said to present a weak drift (page 427 line 9-10). This sounds contradictory and why is the drift in the first 100 years in CTRL not seen in Fig 3a?

R3 => We have removed "until the model reaches a stable state". In Fig 3a, the drift does not appear at the beginning of the simulation because the time series of the Northern Hemisphere (NH) temperature of SGI and CTRL have been detrended with the low frequency trend estimated in CTRL. To clarify it, we have replaced "removed it from SGI" by "removed it from SGI and CTRL for the following analyses" at the last sentence of Section 2. We have also added the low frequency trend in Fig 1.c to show what has been removed from the SGI and CTRL time series.

C4 => The sentence on page 427/428 line 29/1 should say that the radiative forcing is null when averaged over the year and over the globe and not when averaged at hemispheric scale. The annual and global insolation received at the top of the atmosphere does not change with changes in precession or obliquity, but changes only with eccentricity which is negligible over the millennium period.

R4 => We changed "The associated radiative forcing is null when averaged at annual and hemispherical scale, but is not negligible when considering high latitudes and seasonal means (Fig. 1)" for "The associated radiative forcing is null when averaged at annual and global scale (only influenced by changes in eccentricity, negligible during the last millennium), but can be important when considering high latitudes and seasonal means (Fig 1.c))".

C5 => The simulation SGI does not account for volcanic activity and land-use changes

which are considered in many previous climate simulations for the past millennium. Is there a reason to omit these forcings? On page 430 line 13-17, the volcanic forcing is shown to produce an even better agreement with reconstructions in the industrial period after 1850.

R5 => Solar and volcanic forcings are the principal forcings suspected to have played an important role in driving the climate during the last millennium. Since our simulations are the first simulations of the climate of the last millennium with the IPSLCM4 model, we wanted to test separately both forcings to study their model response. Because of computational resource, it has not been possible to run a simulation for each forcing separately, i.e. TSI variability, CO2, orbital forcing, land use and volcanic forcing. The SGI simulation was performed to focus mainly on the influence of solar variability during the last millennium in the model, free of volcanic forcing. The variations of CO2 concentrations are often presented as a feedback to temperature variations, and have been accordingly taken into account in SGI. Orbital forcing has a minor importance at global scale, and was easy to be taken into account. This simulation was an opportunity to study the model response to the slowly varying forcings, like TSI, CO2 and orbital forcing, and their ability to reproduce the secular patterns like the MCA and the LIA. The impact of volcanic forcing during the last millennium in the model is currently studied in another simulation. Concerning the impact of the land use, it is known to have influenced the MCA-LIA transition over Europe in previous numerical studies, as mentioned in our introduction (p 424-425 | 28-29-1-2). It will be implemented in further simulations with the IPSL model.

C6 => The significance of the linear decomposition of the temperature response in relation to TSI, GHG and orbital forcings is shown to depend on the spatial resolution and on the region. In some regions localized processes come into play, e.g., the ice-albedo feedback in high northern latitudes or the ENSO dynamic. In addition, the dissimilar latitude-month patterns of TSI and GHG forcings alter the relative influences from TSI and GHGs on the temperature response which is not discussed. I can imagine that different forcing patterns can contribute to the differences seen in Fig 6 between C_1BV and C_2BV in the high northern latitudes. While C_1BV is relatively large in the northern latitudes in northern summer, C_2BV is relatively large both in summer and winter. The different forcing patterns could also play a role for explaining the percentages of the temperature variance shown in Fig. 7. See for instance Fig 1 in Govindasamy et al (2003) and the discussion therein.

R6 => Thank you for this interesting comment. We have revised the text of the page 437, lines 1 to 25, to take into account the discussion elements you brought. Please find the revised text in the following part. "The sensitivity patterns (Fig. 6) associated with TSI and CO2 show the highest values in the Polar Regions. This is likely due to the albedo feedback associated with sea-ice, especially in the Northern Hemisphere. The differences in sensitivity to TSI and CO2 between JJA and DJF can be partly explained by the latitude-months forcing patterns associated with variations in TSI and CO2, as illustrated in (Govindasamy et al., 2003) and (Dufresne et al., 2005). The sensitivity to TSI (C1) is important in the tropics ($\sim$0.2°C/Wm-2) and of comparable amplitude on annual, summer and winter averages likely because the solar radiative forcing is almost constant with the seasons in this region. In the Northern high latitudes, the model sensitivity to solar forcing shows strong differences between summer and winter, reflecting the seasonal dependence of solar forcing with the latitude. The sensitivity to CO2 shows less contrasted patterns between summer and winter in high latitudes than sensitivity to TSI variations. This is consistent with the weaker seasonal cycle of the CO2 radiative forcing in the Arctic region. In the Southern Hemisphere the ocean-atmosphere-sea-ice dynamics around Antarctica generate important decadal to multi-decadal variability and the significant coefficients are restricted to small areas. The slope C3 shows the higher values in the Northern Hemisphere during summer and the highest values in the Arctic. On annual and winter mean the C3 values do not show any latitudinal coherence, denoting that those trends are probably not linked to orbital forcing. The temperature variance in SGI (Fig. 7) is the strongest in the high latitudes as well as the sensitivity to TSI, CO2 and orbital forcing. The amount

of variance explained by the signature of solar forcing in SGI is not strictly following the values of sensitivity to TSI variability. The temperature variance in the equatorial band is particularly affected by solar forcing because solar irradiance is high around the equator. The signature of TSI explains more than 50% of the temperature variance in the Western Pacific Ocean (Warm Pool), the Indian Ocean and the Equatorial Atlantic Ocean. It has lower impact in the Arctic despite higher sensitivity values. It explains more than 10% of the temperature variance over most of the continents on annual average, in North and South America, Africa, and Southern Asia. It is weakly significant over Europe on annual average and winter, and the variance of its signature can reach 25% of temperature variance in summer. At mid-latitudes, the variance explained by solar forcing in winter and summer follows the associated sensitivity patterns."

C7 => Why is in the definition of SNR (Equ. 4) the weighting of the elements depending on a length scale (sqr t(a_i)) instead depending on the area (a_i)?

R7 => We apologize for this mistake. We initially wanted to apply the weight on the temperature time series, which was not correct. The SNR presented on Figure 5 was calculated with the good formula, without the root-mean-square on the weights ai. Eq. 4 has been corrected.

Technical corrections:

p 425 l 17: change "until" to back until or since => "until" was replaced by "back until"

p 429 l 2: The order of the authors Wahl and Ammann are interchanged, see also reference list. => The order of the authors has been changed for "Ammann & Wahl". The acronym "WA07" has been replaced by "AW07".

p 431 l 14: Is it more adequate here to say: We calculate the signatures associated to TSI (S_TSI = ...? => Yes it is. We replaced "We calculated the variance of the signatures associated to TSI" by "We calculated the signatures associated with TSI".

p 432 l 14; p 436 l 22 and p 437 l 4: unit of sensitivity C_1 in C / Wm-2 => The corrections have been done to have C1 in °C/Wm-2

p 432 l 15: change F_3 to S_3? => F3 (old notation) has been replaced by S3

p 432 l 26: change reproduced to repeated => “reproduced” has been changed by “repeated”

p 436 l 6: Does the term "frequency of the variability" here refer to the time-window of smoothing? => “The slopes of the SNR curves are too low around the significance level to determine the dependence between the characteristic spatial scale and the frequency of the variability considered” has been replaced by “The slopes of the SNR curves are too low around the significance level to determine the dependence between the characteristic spatial scale and the frequency of the variability (determined by the smoothing) considered”

p 432-433 : The different variances of the signatures described in the text for the two time sections (1000-1425 AD and 1425-1850 AD) should be given in an extra table. => Table 2 has been added, and contains the variances of the forcing signatures estimated with univariate and bivariate linear regressions, on the whole period, the 1000-1425 and 1425-1850 AD period.

Fig 1a: Orange line is hard to see => The colors in Fig 1 have been changed for a better presentation.

Fig 1a caption, p 451: TSI values are shown on the right not left of figure “Left” has been replaced by “right”

Fig 4: What is the meaning of the colors on the globe? => The colors represented the surface temperature climatology in SGI. We have removed the colors in Fig. 4 to avoid misleading information.

Fig 5: An alternative to "spatial extend" is maybe geographic dimension. => “spatial extent” has been replaced by “geographic dimensions”.

Fig 6 and 7: Change summer to maybe JJA and winter to maybe DJF => We have added “JJA” and “DJF” next to “summer” and “winter” respectively in Fig. 6 and 7.

Interactive comment on Clim. Past Discuss., 6, 421, 2010.

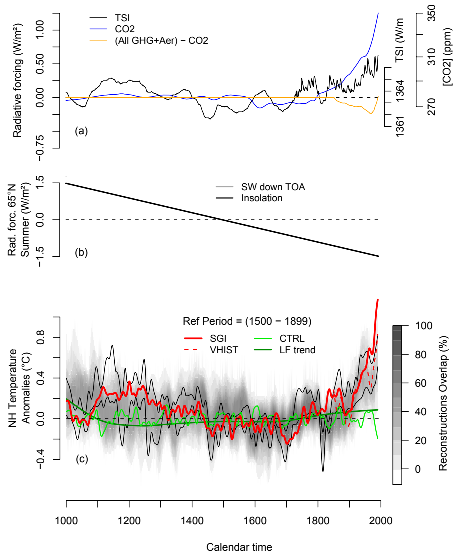

Fig. 1. Revised Fig.1

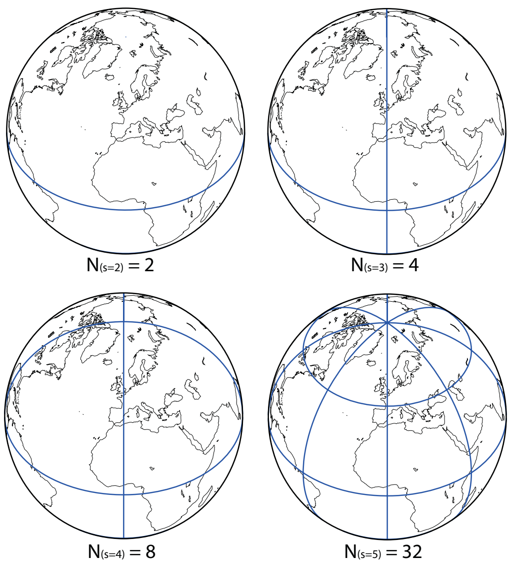

Fig. 2. Revised Fig.4

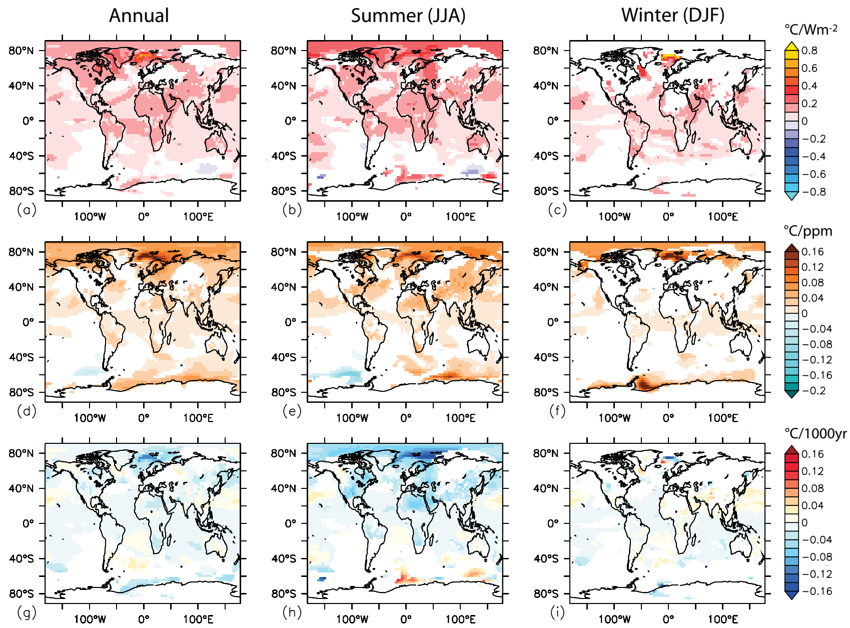

Fig. 3. Revised Fig.6

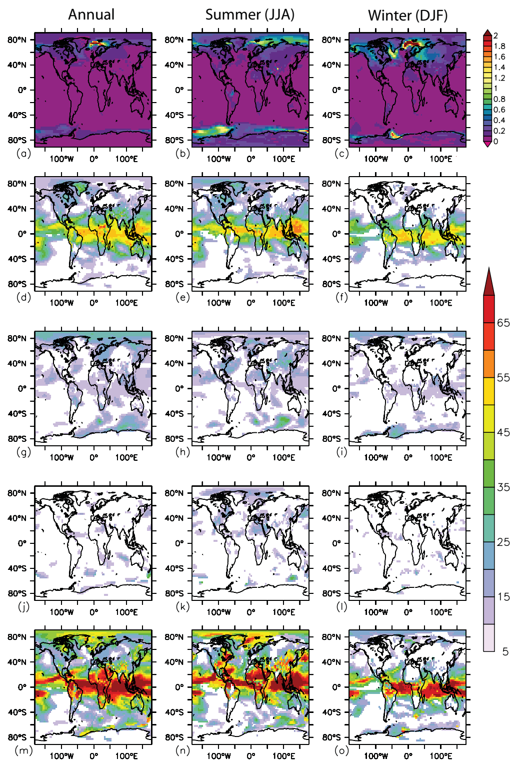

Fig. 4. Revised Fig.7