

Review of Clim. Past. Discussion: doi.org/10.5194/cp-2018-59:

Contribution of sea-ice albedo and insulation effects to Arctic amplification in the EC-Earth Pliocene simulation

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General Comments:

I recommend this work being accepted only after major revisions and rewriting for improved English composition. The late Pliocene is a unique warm period, representing a climate in equilibrium to modern levels of atmospheric greenhouse gas concentrations. This study makes a contribution to understanding the impact on sea ice response to Arctic amplification in a past warm climate state for which there is a large body of climate proxy data and other model studies. Most of the results shown here concerning the decomposition of the effects of sea-ice change on Arctic amplification are not new, as discussed in Serreze and Barry (2011), though the methodology, of using CFRAM may be new to this particular application. As this work pertains to a Pliocene simulation that compares well to the proxy-reconstruction, it would make a good contribution to the literature. More details of the CFRAM methodology used in this application would be beneficial to the readers.

Specific comments:

This manuscript needs to be thoroughly edited by someone with more English proficiency in order to improve the grammar and many awkward sentence structures. The result would be greater clarity for understanding the methodology and results. As written, many sections are not written with the necessary clarity for communicating the authors' intent. I point out some examples in my detailed comments by line number, below.

A TOA net energy imbalance of about -0.5Wm^{-2} (Fig. S1) is large and suggests the simulation is not at a near equilibrium. In addition, the weak negative trend in the TOA energy imbalance suggests the model is moving away from equilibrium. Is this not globally integrated? A net loss of energy at the top of the model is inconsistent with both a positive SST trend and a negative sea ice concentration trend, both of which suggest the model is warming, unless a negative TOA flux is directed downward. This figure needs more explanation.

Overall, there is a general lack of specific details of the analyses presented. For example, how are the anomalies computed, i.e. are trends first removed? A more physical explanation is needed for why you are using spatial correlations because as written, "limitation of data and computation" is quite vague. More detail is also needed to explain how CFRAM was applied to the surface energy balance in the Arctic. For example, what is the "first part of CFRAM" (line 143) used to obtain the surface radiative fluxes. Some equations would be useful, as would a citation to the same specific use of CFRAM as applied here.

More detailed comments by line number: (Note: this is not a complete list of every grammatical issue in the text.)

11: "current warming climate" suggests transient climate change.

14: Define PRISM and give a citation.

17: "Given the facts..."

19: Run-on sentence structure.

20: During winter months...

29: Either "...in the recent decade..." or "...in recent decades..." "Moreover, an ice-free Arctic..."

31: "As the sea ice retreats..." Isn't it the average reflectivity of the surface that decreases due to a decrease in the fractional sea ice coverage and a decrease in the sea-ice albedo due to melting snow and ice. Are these two effects separated out here? For improved clarity it might be better to say "As sea ice retreats, the surface Arctic Ocean becomes less reflective and the enhanced open ocean region leads to greater air-sea heat exchange due to the reduction in the insulating effect of sea ice." However, as sea ice melts, its reflectivity changes and as the sea ice concentration changes the surface albedo is impacted. Both of these changes affect the net shortwave radiation at the surface.

"This leads to changes in the surface heat budget and changes in..."

33: "...possibly results from..."

38: "...consequence...has been reviewed"

46: shown

57: First "attributions" should perhaps be "characteristics" or "properties". Second "attributions" in line 59 should perhaps be "effects" or "mechanisms" here.

59: Run on sentence. I suggest cutting into two separate sentences or using a semi-colon instead of the comma after "...atmosphere and ocean"

69: should be "effects"

78: "represents"

79: Should amend "future climate at equilibrium with modern ghg levels"

138: "temperature"

143: "first part of CFRAM" is vague. More details on how CFRAM is applied should be given here.

169: Replace "present" with "modern", omit "benthic,"

170-174: Make a stronger statement linking the Arctic amplification statement starting on line 174, because that is the focus in this paper. To do this, I suggest rewriting here. I also suggest that you omit describing the tropical anomalies mainly because it is irrelevant to this work. Also, see Scroxton et al., *Paleoceanography* (2011); Brierley, *PAGES News*, 21(2), (2013); Watanabe et al., *Nature*, 471, 209-211, (2012); for recent papers discussing evidence for a robust Pliocene ENSO.

176-177: "...even though they have comparable CO₂ concentration..." replace with "...despite comparable CO₂ concentrations..." I also suggest breaking this sentence into two after the Ballantyne citation. Then in the next sentence suggest possible reasons why there is enhanced Arctic warming or amplification compared to today. I would add these newer citations for the amplified response to closed gateways: Otto-Bliesner et al. *GRL*, 44, 2017 and Feng et al. *EPSL* 466, 2017.

187: Omit the brief, sentence starting in line 187 with, “Meanwhile...” because the paper’s focus is on the Arctic response.

192: “region” should be “regions” and omit “but they are apparently” for improved conciseness.

194: “Noteworthy...” Awkward. A potential replacement is “Notably”

194-195: Suggest replacing “...SAT, and the maximum...” with “SAT; the maximum...” using a semi-colon to join the two clauses instead of the conjunction “and”.

197: The first line of this paragraph contains little meaning.

204:208: An equation for the net air-sea heat flux with the components presented symbolically is written in equation (4), but then these symbols are never used again, and reference to (4) is never made. I suggest removing the equation and stating this decomposition elsewhere. Also, what about the ice-ocean heat flux? A surface heat budget for the Arctic ocean should include the ice-ocean heat fluxes associated with the freezing and melting of sea-ice.

209-218: This paragraph discusses the anomalies or differences in the heat flux components in the Pliocene simulation as compared to the Preindustrial simulation, not heat fluxes. Every mention of a flux in this paragraph should reflect the fact that what is discussed are differences in the flux.

210: “The radiative and turbulent heat fluxes...” These are differences or anomalies.

211: “...the positive shortwave radiation is dominant...” should be “...the positive change in the shortwave radiation is dominant...”

212: “On the contrary” should be “In contrast”

220: “accounted as the synergy...” Awkward phrase. Suggest a rewrite of the first paragraph of this section for better clarity and conciseness. The definition of albedo needs to be more precise, to distinguish from planetary albedo.

224: relevant to net shortwave...

225: Be more specific: net shortwave flux at the surface... Also, is this due to changes in sea-ice and snow albedo (that is, changes in the albedo due to changes in the state of sea-ice or snow, or to the change in albedo over the ocean grid box due to both albedo change and change in sea-ice concentration?)

226-227: “...most...shows...”

227: net shortwave

229: changes in sea ice extent

231: changes in snow cover ... (and, I presume, any change affecting the actual sea-ice albedo which could be changes in the sea-ice or snow state, such as melting, because the albedo is a function of the sea-ice state as well as thickness according to earlier descriptions of LIM.)

233: net shortwave

234: “Regarding the...” This opening sentence is awkwardly stated and vague.

235: *net* shortwave radiation, i.e. shortwave radiation absorbed?

238: “The prominent oceanic heating in May and June seems inconsistent with the maximum SST warming in August,...” Second clause of sentence seems to explain why the SST warming lags the SW heating response, thus it is not “inconsistent” but “consistent.”

240: About the SIC anomalies: Shouldn't this be something “like the mean spatial variance over the Arctic of the Pliocene SIC anomalies is not strongly variable over the mean annual cycle.”

This is a curious result. A nice additional supplemental figure could show the Pliocene anomaly pattern at the minimum and maximum of the SIC annual cycle.

243: “our correlation analysis indicates that...”

246: Needs to be more specific: ...seasonal cycle of incident shortwave or net shortwave? ...sea ice concentration variation, or some other sea ice property variation?

250: ...insulation effect of sea-ice...

251: omit “In fact,”

251: “insulation effect”

250-255: This first paragraph should be rewritten. The insulating effect of sea-ice has an indirect effect on the net surface shortwave and longwave fluxes. By separating the overlying atmosphere from the ocean, sea-ice reduces evaporation from the ocean resulting in a decrease of water vapour and cloud cover. This reduction plays a non-negligible role in the amount of downward shortwave and longwave radiation reaching the surface. However, remote moisture transport also affects water vapour and cloud amount. Thus, ...

256:262: It is not clear in this paragraph whether the discussion is about the SW and LW feedbacks after the remote effects on clouds and water vapour have been removed. This is suggested in the Figure 7 caption however.

258: ...cloud characteristics...

263:274: Then this paragraph discusses just the local effect due to changes in sea ice concentration? I don’t know what is meant by “counterpart of sea-ice insulation.”

264: “Like the steps performed to isolate the albedo effect...”

266: “In the annual mean...”

270: “...shows a pronounced...”

271: “Compared to...” And this is being compared to the standard deviation of the shortwave anomalies due to clouds? Also, should be “SIC anomalies” and

272: Net shortwave radiation change and net longwave radiation change?

274: ...when there is a lack of...

279: ice-free conditions

280: the insulation effect

280: ...and differentiate fluxes from ice-covered versus ice-free areas, not “ice-covered fluxes”

281: displays the Pliocene anomalies in ...heat fluxes...as a function of SIC anomalies.

282: There is a larger spread in the turbulent heat flux anomalies over the ice-free area (grey symbols, corresponding to the diagonal hatched region in Figure 2c) than compared to anomalies from the ice-covered areas (light blue symbols, cross-hatched region in Fig. 2c) because the former is free from the constraint of sea-ice.

284: ...and changes in SIC...

285: Are these estimates of variance explained from the regression lines shown in Figure 9? Is this and the response coefficient shown in the figure just for the ice-covered region? Be specific in both the Figure caption and the main text.

286:293: This paragraph jumps all over the place and is very unclear. First it discusses annual mean response coefficients vs. trends elsewhere, to the y-intercept of the regression line, then jumping to explaining seasonal variation.

287: Noteworthy—a better choice would be “Notably” as mentioned previously.

288: “trend of sensible heat flux” this comes out of nowhere, to what does this refer? Is this “trend” referring to 20th century trends observed? Describe accurately.

289: ...turbulent flux anomaly axis?

290: “even without SIC change” for improved conciseness.

294: ...to the sea-ice concentration? Or to sea-ice changes in general (thickness, albedo, concentration, etc.)? Also, replace “two” with “the”.

295: “...have a similar...” and “...showing a negative response...”

296: “...maximum warming of SAT occurs in November as a consequence...” It looks like changes in the net LW due to the response of clouds and water vapour is also a contributing factor to the warming in fall. As a complete budget for SAT is not presented, it would require adding heat transports and other fluxes, one can only suggest contributing factors.

Section 6 Summary and Discussion;

This section is mostly a summary of results. Additional discussion could compare these results to previous results (see Serreze and Barry, 2011), could compare to the other Pliocene simulations which showed weaker Arctic amplification, highlight what is new here, etc.

304-309: Paragraph should be rewritten as it contains many awkward phrases. Also, I disagree that a model ever reveals a complete picture, but a model may be applied to investigate mechanisms and processes that help in understanding.

312: “...the effects of changes in”

314: “...expected to partly interpret the variability of heat flux” Very unclear as to what this is supposed to mean.

315-328: This paragraph appears to summarize the albedo and the insulation effects of sea ice on surface heat fluxes over the annual cycle, but doesn't seem to say anything about the Arctic amplification noted in the comparison of the Pliocene to preindustrial climate simulations. This section needs to be more specific.

326: sea ice decline...Is this the decline of Pliocene sea ice as compared to the preindustrial, or over a seasonal cycle? It is not clear whether anomalies are being discussed. Also, “accelerates” should be “amplifies” as “accelerates” suggests time evolution, and here equilibrium runs are being discussed.

Comments on Figures:

2) Please make the hatching in 2c more visible with another color or thickness. Be specific about describing the heat flux. “Net heat flux at the surface” Is this net heat flux at the surface (ice and ocean), or net heat flux at the surface of the ocean (air-sea and ice-ocean interfaces)?

3) State when the flux is a “net” flux change, that is for the sw and lw fluxes.

4) Be more specific. Does the figure show the change in mean annual net shortwave flux at the surface?

5) and 6) net shortwave flux, also in 5) and 9) “All changes are” or “All change is”

- 7) More clarification is needed in the figure caption. Also, “caused by” should be “related to”, because causality is difficult to attribute in feedback processes.
- 8) Specify “net” again. Also, “caused by...” should be “related to...”.
- 9) Define ice-free vs ice-covered regions here referring to Fig. 2c. Also...“Pliocene changes shown are computed relative to the preindustrial simulation.” Describe the regression lines, i.e. which set of scatter points are being regressed. “caused by” should be “related to”.
- S1) Are all of these quantities global averages?