Dear Dr. Freese:  
  
Thank you for submitting "Antarctic Radiative and Temperature responses to a doubling of CO2" [Paper #2021GL093676] to Geophysical Research Letters. I have received 2 reviews of your manuscript, which are included below and/or attached. As you can see, the reviews indicate that major revisions are needed before we can consider proceeding with your paper. I am therefore returning the paper to you so that you can make the necessary changes.   
  
  
  
Please submit a revised manuscript that addresses the reviews and any editorial comments by May 22, 2021.   
  
In your revision, please follow our [Checklist](https://www.agu.org/Publish-with-AGU/Publish/Author-Resources/Revisions-Resubmission-Checklist) and use our [Templates](https://www.agu.org/Publish-with-AGU/Publish) for the main file and any supplements. Please provide the following:    
  
1. A response to reviewer file that lists each major comment and describes how the manuscript has/has not been modified in response to those comments.  
  
2. A copy of the manuscript with the changes noted (e.g., highlighted, "track changes," italics or bold changes).   
  
3. The final revised manuscript with changes incorporated and separate final figure files (figure parts should be combined into a single file), which will be used for publication if the manuscript is accepted. If final figures are already uploaded, they can be easily copied over to the next revision version.  
  
4. If any, supporting information text, figures, captions, and small tables in single PDF file using AGU's template. Large data tables and multimedia should be uploaded separately.  
  
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Please check and verify authorship, and that all authors are included, have approved the revisions, and agreed to be listed in the order given. Authorship is final with publication. Responsibilities of the corresponding author are given [here](https://publications.agu.org/author-resource-center/text-requirements/).  
  
When you are ready to submit your revision, please login to your account (<https://grl-submit.agu.org/cgi-bin/main.plex>) and click "Revise 2021GL093676."   
  
I look forward to receiving your revised manuscript. If you have any questions, or need additional time to complete your revisions, please contact us at [grlonline@agu.org](mailto:grlonline@agu.org).  
  
Yours sincerely,   
  
Gudrun Magnusdottir  
Editor  
Geophysical Research Letters   
  
------------IMPORTANT INFORMATION------------------------    
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----------------------------------------------------------------------  
Reviewer #1 Evaluations:  
Science Category (Required): Science Category 2  
Presentation Category: Presentation Category A  
Key Points (Required): Yes  
  
Reviewer #1 (Comments to Author (shown to authors):  
  
This paper addresses an interesting problem in climate science: the surface warms in the Antarctic despite a negative (cooling) CO2 radiative forcing measured at TOA. The failure of the TOA forcing to predict the direction of surface temperature change poses a challenge for climate scientists to explain. This paper attempts to reconcile the problem from a surface energy balance perspective and uses a simple model to test their interpretation. Overall, I find the paper interesting to read and potentially a valuable contribution, as it brings this interesting problem to more attention and proposes a theory to explain it. However, a few issues need to be rectified, especially concerning the validity and relevance of the modeling results.    
Supplement -model validation

Correction in text

Main comments  
  
1. Clarity and validity of the model   
Paragraph after line 100. Is cloud included in the calculation? What vertical resolution is used, especially close to surface? Is shortwave included? What surface albedo is used in shortwave?... In general, there lacks sufficient description and validation of the simulation of the local climate, especially concerning radiative fluxes. Potential biases due to parameter choice, as well as the use of monthly mean profile, should be noted and discussed.  
We’ve added clarifications about clouds, which are not included in the calculation (paragraph after line 101); vertical resolution, which varies with height (line 101); inclusion of shortwave and the surface albedo (paragraph after line 101). Additionally,

Similarly, concerning the advective and turbulent heating, there ought to be proper illustration and validation of the relevant modelling components. For instance, the profiles of heating rates due to different components, as well as the TOA and surface energy flux values.   
In order to better validate the model, we have included a comparison of the surface and top of atmosphere long and short wave fluxes to monthly observations from CERES from 2000-2020. We have also clarified the closure of the energy budget. Regarding comparison to advective and turbulent heating profiles, since our advective profile is the residual heating needed based on observed temperature profiles, comparisons to any observations would similarly just be made through calculations of the residuals due to temperature profile changes. This would, therefore, be almost the same calculation as is performed to calculate the advection itself.   
Another issue is that the method and model descriptions miss necessary references of the ideas and equations. A few specific notes are given below:  
Paragraphs starting at Line 103: Concerning the forcing dependency on CO2, it is proper to note the idea that explains the forcing as resulting from the vertical displacement of the radiating level and thus naturally dependent on the lapse rate (Huang & Bani shahabadi, 2014, doi:10.1002/2014JD022466). This is a fundamental reason for the negative forcing in Antarctic, as well as sometimes found in winter Arctic when strong inversion occurs (i.e., when lapse rate reverses the sign) (Huang et al. 2016).   
This point has been addressed in lines 118-122, where we discuss the dependence of the forcing on the vertical displacement of radiating level, as well as including a point on the negative forcing that occurs under strong inversions.  
Paragraph after Line 115  
Regarding the "effective height for emission": If the vertical resolution is coarse, the model can't resolve the change in the emission height, although strictly and theoretically speaking it should be sensitive to CO2 perturbation. With RRTMG, one could analyze the forcing, as well as related band averaged radiative properties (e.g., optical depth), in different bands. One suggestion is to contrast CO2 band 630-700 cm-1 to the surrounding bands (500-630, 700-820 cm-1) to validate these approximations.    
Thank you for this helpful suggestion. The current use of RRTMG does not allow us to contrast different wavelengths of CO2 bands, so we cannot analyze the forcing through this method. We’ve clarified the language in this part to make it clearer that the assumption regarding the effective height for emission means that we can use the surface temperature as a proxy for the emission temperature, which should resolve the issue pointed out that a model may not resolve changes in emission height, as we are not aiming to resolve that in this simplified equation.  
Line 117: 10.4 cm-1 - reference to this number? What frequency is it pertinent to?   
Reference to Jeevanjee, 2020 is now made clearer, and the frequency is added in line 125.  
Line 137: this temperature jump phenomenon was documented as early as Manabe & Stricker 1964.   
Reference added in paragraph after line 146. The temperature jump phenomenon is slightly different between the two scenarios, as in Manabe and Stricker, the temperature jump is not physically realizable/stable without the addition of convection/turbulence.  
Eq. 6: reference and rationale to this formulation, including the k(z) expression and choice of d=100m?  
  
  
Eq. 4: Pierrhumbert (2010, Principles of planetary climate) should be cited as the original formulation of this group of idea that derives the log relationship from spectrally averaged perspective, i.e., based on such radiative properties as bandwidth; this is distinctive from the idea that is based on the spectrally resolved radiance and interprets the forcing as resulting from the displacement of emission level (Huang & Bani Shahabadi, 2014).   
Descriptions and references have been added in the paragraph preceding equation 4.  
  
2. Relevance of the model and results   
Given that this is a single point-based toy model, how much can the results be related to the reality? Some proper discussions are necessary to note what findings are robust and generalizable and what may be subject to caveats. For example, the limitation(s) of fixing advective heating, which in reality may vary and lead to surface warming. And also fixing the turbulent parameter K0 and limiting the turbulent flux to the lowest ~100m.   
We’ve discussed the limitations of a fixed heigh scale, as well as briefly discussing some of the sensitivity tests we have performed to test the impact of changing the height scale on the results in line 150. Additionally, we have added in a discussion on the limitations due to a fixed advective heating profile starting in line 159.   
Additional comments  
  
Paragraph after Line 100: What values are included in the "range of CO2 values"?  
Exact values of CO2 that are used are now provided in the paragraph after line 101.  
Fig 1 and other line plots: it would be easier to use log scale on x-axis for visualizing and testing the log relationship.   
We’ve adjusted the plots that have varying CO2 levels to have log scales on the x-axis.  
Line 160. It would be relevant to compare to Wang & Huang (2020, doi:10.1175/JCLI-D-19-0032.1), whose fig 4b showed qualitatively similar results with more sophisticated single column simulation. This result seems to corroborate the statement here and helps to verify robustness in this result.   
Thank you for pointing this out—we’ve added a citation to Wang & Huang for the discussion on the response to CO2 (line 171).  
  
  
Reviewer #2 Evaluations:  
Science Category (Required): Science Category 1  
Presentation Category: Presentation Category B  
Key Points (Required): Yes  
  
Reviewer #2 (Comments to Author (shown to authors):  
  
This paper explains why, even though adding CO2 increases outgoing longwave radiation (OLR), it still warms the surface in Antarctica.   
  
They show that, if CO2 is varied independently, the top-of-atmosphere (TOA) greenhouse effect (GHE) decreases for all seasons except the austral winter months, whereas the surface GHE increases for all months. Using the fact that the Antarctic atmosphere is in radiative-advective balance and that the coupled boundary layer and surface system can only lose heat by upward radiation, they derive a simple expression for surface temperature change that depends on CO2 concentration and initial surface temperature. They then use a radiative-advective-turbulent single column model to verify the accuracy of their simple derivation.  
  
I have a few minor comments but think the paper is very good and I recommend publication after addressing my comments.  
  
Comments  
  
Fig 1: Can you comment on why GHE sfc is much higher in December than the rest of the year. Is it just that surface temperature is higher in December (equation 3)?  
We’ve added this explanation into the caption of figure 1.   
L. 95 CO2 → O3  
We’ve modified this to O3.   
L. 138: Why are there only nine positive values? Are these the months with an inversion?  
  
Eq 10: what is t? And is it not dFadv/dz?  
We’ve defined t as time. In the model, we are calculating a heating rate and prescribing a flux based on that, so the direction of the advection is not of particular importance. Since the advection term has no directionality, we assume the majority of it would be due to meridional heat transport, therefore we have it in the y direction.   
L.167: Shouldn't it be delta GHEsfc? It does say "relative to \*no\* CO2" but other components contribute to GHEsfc such as water vapor, so I am a bit confused here.  
We’ve adjusted this to be delta GHEsfc.  
Fig 3b : I find this graph hard to read. Maybe you can bundle the months by 3? DJF, JJA, etc.  
We’ve modified this to bold the months highlighted in other graphs, and have also moved it to Figure 1 in order to address questions brought up by other reviwers.  
Can you comment on the relevance of these results to the Arctic?

We’ve added a brief comment on the relevance of these results to the Arctic in line 206, particularly noting the role of the GHEsfc.