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Interactive comment on "Examining the role of varying surface pressure in the climate of early Earth" *by* Junyan Xiong and Jun Yang

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Xiong and Yang presented interesting modeling results on the role of varying surface pressure in changing Earth's temperature, which have implications on the "faint young Sun paradox". The authors' calculations using 1-D radiative-transfer model and 3-D general circulation model (GCM) suggest that increasing surface pressure warms Earth's surface due to a stronger pressure broadening effects associated with greenhouse gases. For example, their GCM simulations show a climate sensitivity of $\sim$10 K per doubling or halving surface pressure. Role of ocean heat transport is also discussed.

The manuscript is in general well-written and easy to follow. The research topic is interesting and adds to the discussion on mechanisms for the evolution of Earth's climate. However, this manuscript in its current form is very descriptive and lacks in-depth analysis to clarify contributions from different feedback processes and to better support the authors' interpretation of results. For occasions, a more detailed description of model and experimental setup is needed. These issues should be resolved before the manuscript can be published in Climate of the Past. Please see my detailed comments below.

Major comments: 1. The radiation calculation. The authors fail to provide necessary information for readers to assess the performance of their radiation schemes in the 1-D model and the GCM. How complex is the 1-D radiative transfer model? Have the authors validated the solution against comprehensive line-by-line calculations? Related information is also required for assessing the highly parameterized and tuned radiation schemes in GCM, especially when the authors are using them well away from the climate conditions for which they were tuned. Another related question, is the radiation scheme the same between the 1-D model and the GCM?

2. On multiple occasions, the authors attribute the temperature changes in their simulations to climate feedbacks, such as ice albedo, water vapor, and cloud feedback, but fail to substantiate their claims in a quantitative manner. I understand that a complete feedback quantification for multiple GCM simulations demands large amounts of resources, but there are cheaper solutions, e.g. the approximated partial radiative perturbation (APRP) method (Taylor et al., 2007). Although not providing a complete quantification, APRP can quantify the shortwave feedbacks really well, which, in my opinion, will offer important insights on temperature responses in the authors' simulations.

3. Role of ocean heat transport (OHT). Based on the description of experimental design, it is unclear how the mixed layer depth is prescribed, a constant everywhere, or a present-day spatial distribution? The authors have acknowledged the limitation of their approach using a slab ocean model with prescribed OHT (e.g. last paragraph on Page

13), but more discussion should be added on this. First, changing OHT while fixing the mixed layer depth is not a physically consistent approach. Ocean circulation and heat transport are usually accompanied with distinct ocean structures including mixed layer conditions. For example, ocean circulation and heat transport are greater in the present-day North Atlantic, so is the mixed layer depth. Second, the physical consistency between the prescribed OHT and the climate state should be better discussed. Is an OHT of 0.5–1.0 times the present-day value possible under a cold climate with a global mean temperature of $\sim$210K? Similarly, are the OHT values realistic in a warm climate of $\sim$326K? How does a snow/ice cap impacts OHT? Is it possible that warming and freshening under a warm climate increases the ocean stratification and decreases the high-latitude OHT, making some of the authors calculations unrealistic?

Minor comments: 1. Page 1, Line 23: a low-δ18O sediment infers a high ocean temperature 2. Page 2, Line 1–4: Another important caveats regarding the isotopic thermometry is the assumptions on isotopic composition of seawater, i.e. a low calcium δ18O may reflect a low seawater δ18O. This should be added to the discussion. 3. Page 3, Line 3–28: Poulsen, Tabor, & White (2015) is worth mentioning when reviewing findings in previous studies. 4. Page 5, Line 3: I would not say the application of CCSM3-CAM3 was successful for the Eocene. Caballero and Huber (2013) and later studies clearly showed that Eocene climate in CCSM3 is too cold when the estimated Eocene CO2 is used. 5. Model description: Please add information on model resolution and integrations length. Have the slab ocean simulations reached equilibrium? 6. Page 8, Line 22–23: the atmospheric energy transport change little when the surface air pressure is varied. 7. Page 8, Line 25–26: the meridional atmospheric energy transport does not change much. 8. Page 8, Line 29: Besides the warming of the global surface.

Reference: Taylor, K. E., Crucifix, M., Braconnot, P., Hewitt, C. D., Doutriaux, C., Broccoli, A. J., ... & Webb, M. J. (2007). Estimating shortwave radiative forcing and response in climate models. Journal of Climate, 20(11), 2530-2543.

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