Reply to Comment on "Clouds and the Faint Young Sun Paradox" by Goldblatt and Zahnle (2011)

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Rondanelli & Lindzen (2011, RL11 hereafter) comment on section 6.1 of our paper (Goldblatt & Zahnle, 2011, GZ11 hereafter), in which we criticized their earlier argument (Rondanelli & Lindzen, 2010, RL10 hereafter) that enhanced cirrus could provide a unique solution to the Faint Young Sun Paradox (FYSP). RL11 divide their comments into three sections, which we follow in our response.

1) We argued that a satisfactory resolution to the FYSP should really provide a surface temperature equal to the present day. RL11 suggest (a) that oxygen isotope constraints which suggest a warm Archean are not reliable, and (b) that it is sufficient to solve a "weak version" of the FYSP, it being satisfactory to have only a small pool of liquid water on an otherwise frozen surface.
   In response to (a), we do not contend this. Hardly anyone in the early Earth climate community takes these results literally, and we do not rely on them. Regarding (b), we are presently in a glacial period, and the glaciers leave a strong mark in the sedimentary record. Glacial sediments are known from the Archean (e.g. In the 2.9 Ga Pongola supergroup) and there is evidence of low-latitude glaciation in the Palaeoproterozoic. However, these are very rare: glacial sediments are absent for the vast majority of the Archean. Discussing this with Archean field geologists, it is appears highly unlikely that this is a simple lack of preservation: there is just far too much "normal" looking Archean sedimentary rock, suggestive of temperate climate (e.g.

Nisbet, 1987). So, a key question to Rondenalli and Lindzen becomes: if you rely on a lower temperature than present, why are there not extensive Archean glacial sediments? Why was a colder world *less* glacial than today? Furthermore, if their proposed mechanism of insulating the Earth is *tropical* cirrus, with little greenhouse gas, would that not lead to colder high latitudes, and more polar ice? What mechanism do they invoke for heating the poles?

2) We questioned the authenticity of the so-called "iris" effect, and noted that the low temperatures they invoke require a very large extrapolation of a claimed empirical relationship, which is unsupported. RL11 responses are: (a) arguing that "the physical mechanism is secondary" to the question of whether cirrus clouds can provide enough forcing to resolve the FYSP without more greenhouse gas, (b) a claim that cirrus clouds can indeed produce enough forcing and (c) saying that they stand by their "iris" hypothesis.

   With respect to (a) and (b) our primary aim in GZ11 was to calculate what forcing any types of clouds could give, and did not posit any particular mechanism for these changes (we did, however, use our analysis to evaluate the viability of recently proposed mechanisms – hence this discussion). Our finding was that more cirrus clouds could – in theory – provide enough forcing to uniquely resolve the FYSP (as opposed to less stratus cloud, which could not). In our model, we have to optimize our cirrus clouds for warming and cover 100% of the sky with them in order to provide sufficient forcing. Both of these would be extraordinary claims, and as such would require extraordinary evidence. We feel that such evidence is lacking both in RL10 and RL11 and that a cirrus-based resolution to the FYSP cannot progress further unless a robust, physically based mechanism is presented. A substantive response to our criticism would need to provide this.

   With respect to (c), the "iris" hypothesis has not received any great degree of acceptance in the meteorological community. This is not the best forum to debate it in detail.

3) In our model, the only way that we could get enough forcing from cirrus to resolve the FYSP was to optimize them for warming and cover the whole sky with them. This end-member case only just provides enough forcing for a unique resolution of the FYSP. RL11 counter this with the argument that some observed cirrus clouds do provide such

forcing and that these clouds do cover 16% of the present-day tropics.
We do not contest the existence of such clouds. Nonetheless, it is a huge leap from 16% of the tropics to 100% of the global atmosphere. When we referred to this as an extreme end-member, it was not in terms of whether isolated clouds like this could exist, but the requirement that the entire planet would have to be covered in such optimum clouds: thick enough and high enough to provide sufficient thermal forcing, but not too thick so as not to reflect too much sunlight. Thinking in terms of the required physical mechanism to support such a hypothesis, it would need to justify not only the 100% sky coverage, but also what feedback mechanisms were keeping these clouds at the perfect height and optical thickness. Can Rondenalli and Lindzen provide a physical mechanism for such feedback?

In conclusion, we do not reject the notion that changes in cirrus cloud could affect the FYSP. More cirrus could help resolve it, but less cirrus would make the problem worse. At the moment, we do not see justifiable arguments in either direction. We agree with everyone involved in this discussion (RL11; Halevy, 2011; Kasting, 2011) that more work on how clouds could have been different in the past is a fertile area of research. Going into this, we need to keep an open mind to the effects that clouds might have – and justify any proposed changes with robust physical mechanisms.

References:

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