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

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Comment on "Clouds and the Faint Young Sun Paradox"

R. Rondanelli and R. S. Lindzen

Abstract

Goldblatt and Zahnle (2011) raise a number of issues related to the possibility that cirrus clouds can provide a solution to the faint young sun paradox. Here we argue that some of the criticism is not warranted. In particular, the criticism related to cirrus clouds being an "end member" case of possible clouds depends heavily on models that may have an inadequate representation of cirrus clouds. Present climate observations show that thin cirrus clouds (optical depth less than 10) can produce positive cloud radiative forcing. When this forcing is represented in models, resulting cirrus clouds are not necessarily realistic. Therefore, cirrus clouds that have a radiative forcing consistent with present climate observations, can provide a solution to the faint young sun paradox, or at least ease the amount of CO_2 or other greenhouse substances needed to provide temperatures above freezing during the Archean.

1 Comments

We wish to comment on some issues raised in the paper by Goldblatt and Zahnle (2011), hereafter referred to as G&Z, in particular to the criticism of our paper in which we explored the plausibility of tropical cirrus clouds as a solution to the faint young sun paradox (Rondanelli and Lindzen, 2010a). G&Z conclude that our solution is not plausible. They base the criticism to the cirrus solution on three main points:

- Colder temperatures in the Archean are not justified from geological evidence, and therefore solutions to the faint young sun paradox that provide a colder climate than present are not satisfactory; only equal or warmer temperature solutions are acceptable.

- The mechanism for the increase in the area coverage of cirrus clouds invoked (the iris hypothesis) is controversial and has been questioned. Moreover, even if

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observed for present climate, such a feedback should have to work for a much colder climate so it would require an unverifiable extrapolation.

- The cirrus cloud used to represent the tropical cirrus clouds that are sensitive to the surface temperature in the 1-D radiative convective model (one that provides a 50 W m^{-2} radiative forcing in present climate) are unrealistic and represent an end member case of all possible cirrus clouds that can be found to have an impact in earth's radiative balance.

The first point relates to the definition of the paradox. A weak version of the paradox would consider the possibility of water in some part of the planet. A stronger version will consider complete absence of ice in the planet. As we explained in Rondanelli and Lindzen (2010a), we find that cirrus clouds in our model are a plausible solution for the weak version of the paradox; that is, temperature above freezing can indeed be found in some region of the planet, in this case in the tropics, for a reasonable strength of the cloud feedback and for the whole time period. And even for the strong version of the paradox, cirrus clouds provide a large increase in the time span at which mean global temperatures are found above freezing. To the extent of our knowledge of the literature, the issue of whether the earth was hot (that is mean global temperatures of about 55 to 85 °C, at about 3.5 Ga, Knauth and Lowe, 2003) or only warm (meaning global temperatures similar to the present) during the Archean has not been settled, given the uncertainties in the oxygen isotopic composition of seawater (see Rosing et al., 2010, and references therein). Kasting et al. (2006) for instance, argue that the isotopic composition of ancient carbonates is not necessarily an evidence for a hotter Archean earth. On the other hand, the absence of evidence of glaciations can not be taken to be a strong evidence for a warmer Archean earth, since climate change is typically characterized by changes in the meridional distribution of temperature rather than uniform changes in temperature. Again to solve the paradox as usually stated, only warm temperatures are required. Consistency between the weaker solar forcing and a hot planet would constitute a much stronger version of the paradox.

With respect to the second point, the physical mechanism invoked is secondary to the original question we attempt to ask. That is whether cirrus clouds as those observed in present climate, can provide enough cloud greenhouse effect as to produce surface temperatures above freezing for a reduced solar insolation such as found in the Archean without resorting to other greenhouse substances. The answer to this question appears to be yes. To be sure, the iris hypothesis can not be discarded as a mechanism operating in the tropics. The challenges to the original observational analysis quoted by G&Z were properly answered (see e.g. Lindzen et al., 2002; Chou and Lindzen, 2005), and evidence for a negative correlation between area of cirrus clouds and sea surface temperature from independent data and researchers has appeared since then (see Rondanelli and Lindzen, 2010b, for the references). Nevertheless, the radiative effect associated with the iris effect, and therefore the magnitude of the cloud feedback remains to be established. However, the point of our original paper was simply to ask the question of how far can the cirrus go into solving the faint young sun paradox, *regardless of what mechanism produced the cirrus clouds*.

Perhaps the most important point is the one related to the realism of the cirrus cloud used as a surrogate for those clouds sensitive to the surface temperature in the model. We choose the cloud not arbitrarily (and certainly not to optimize the warming as suggested by G&Z) but rather to be consistent with the available estimations for the cloud radiative forcing obtained by Choi and Ho (2006). This consistency with the radiative forcing does not imply consistency with the physical properties of the clouds due to inherent difficulties in the modeling of radiative transfer in clouds (e.g. Baran, 2009). Therefore, more important than providing accurate inputs to the 1-D model (that is cloud top, particle radius, optical depth) was to provide a cloud radiative forcing that was consistent with observations. As shown by Choi and Ho (2006) and others (e.g. Kubar et al., 2007), cirrus clouds having radiative forcing higher than 50 W m^{-2} can cover about 16 % of the tropics. Even models allow for net radiative forcings higher than 50 W m^{-2} for a large range of cloud microphysical parameters using a standard tropical atmosphere (e.g. Hong et al., 2009). Therefore the proposition that the cirrus

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clouds used were "end member" cases, might be true for a particular radiative model, but not for what is known from observations.

2 Conclusions

Many interesting ideas arise as one starts considering clouds as a possible solution to the paradox. As G&Z found, clouds modify the impact of other greenhouse substances, for instance, increase the amount of CO_2 required to solve the paradox from what was calculated in simple 1-D models with no clouds. Similarly, as we show in our paper, clouds also modify the strength of the water vapor feedback by altering the surface heat balance (presumably having an impact in the feedback mediated through the inorganic carbon cycle). Since the work of Rossow et al. (1982) it appears that clouds have been omitted from consideration not so much because of their irrelevance but rather because of the difficulty constraining their behavior. We agree with G&Z in the need of including clouds in subsequent efforts to model the problem, we disagree with their assessment on the plausibility of the solution we propose.

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