De 'faint young sun' lastpost

In het artikel van Rosing et al. (2011) wordt aangetoond dat de mineralogie van de afzettingingen uit het Archaïcum, met name de alom aanwezige ijzeroxiode afzettingen met verschillende valentie (Fe (II-III)), niet consistent zijn met hoge concentraties broeikas-gassen in de atmosfeer van dat moment. Hierdoor getriggerd, alsmede door de afwezigheid van ander geologisch bewijs voor de aanwezigheid van zeer hoge gehalten broeikas-gassen, hebben de auteurs de oplossing voor de faint young sun paradox op een andere manier gezocht.

Door te wijzen op een hogere waterspiegel en dus minder landoppervlak, alsmede op de afwezigheid van regendruppel-nuclei (waardoor er minder wolkenvorming zou zijn), zou de albedo van de Aarde, gedurende het Archaïcum, ook veel lager kunnen zijn, dan nu het geval is. Hierdoor zouden er ook geen extreme hoeveelheden broeikasgassen nodig zijn om de temperatuur toch op een redelijk niveau te houden.

Deze hypothese werd onmiddellijk aangevallen door Goldblatt (2011) die in zijn artikel met de veelzeggende naam “Faint young Sun paradox remains” aantoonde dat de benodigde hoeveelheid opwarming, zelfs bij de meest extreme condities, nooit het niveau, wat hiervoor volgens het geologische bewijsmateriaal nodig zou zijn, zou behalen.
Feulner (2012) constateert in zijn evaluatie van de tot dan toe verrichte studies, dat in ieder geval de ammoniak-hypothese, waarvan Sagan en Mullen (en Lovelock) nog uitgingen, op basis van het huidige bewijsmateriaal niet langer kan worden gevolgd. Sagan en Mullen gingen er bij deze hypothese immers nog vanuit dat de aard van de atmosfeer sterk reducerend zou zijn (“the apparent requirement of a reducing atmosphere for the production of organic molecules”).
Deze hypothese moet thans echter als weerlegd worden beschouwd. Albelson (1966) stelde al vast dat bewijzen voor een sterk reducerende atmosfeer tijdens het Archeïcum simpelweg niet konden worden gevonden. Een groot aantal wetenschappers (Walker (1976), Canup, 2004), Hartmann en Davis (1975), Cameron en Ward (1976)) hebben sindsdien de gangbare argumenten voor het bestaan van een dergelijke atmosfeer ontkracht.
Feulner concludeert dan ook: “Thus most of these historic arguments in favor of ammonia (and other reducing greenhouse gases) have now been put into perspective…
Despite its strong warming effect, subsequent studies of the faint young Sun problem revealed difficulties with ammonia as the dominant greenhouse gas in the Archean.
Kuhn and Atreya [1979] used a more sophisticated radiative transfer model and confirmed the results of Sagan and Mullen [1972] … They pointed out one significant problem, however, which had earlier been noted by Abelson [1966]: using models for the photochemistry of ammonia, they demonstrated that the Sun’s ultraviolet radiation (which was much more intense during the Archean…) would have destroyed [the necessary] amount of $NH_3$ via photodissociation in less than a decade…
It should also be noted that ammonia is highly soluble [Levine et al., 1980] and thus quickly rained out of the atmosphere and dissolved as ammonium($NH_4^+$) in the oceans [Kasting, 1982; Walker , 1982].
Due to these problems, ammonia had fallen out of favor as the dominant greenhouse gas in the Archean atmosphere.”
Hoewel Sagan samen met Chyba (1997) nog heeft geprobeerd een oplossing voor de verschillende problemen te vinden, terwijl ook andere studies als Ueno et al (2009) geprobeerd hebben om de ammoniak-broeikas in leven te houden, bleken al deze studies evenveel problemen met zich meebrachten als dat zij hoopten op te lossen. Feulner besluit dit hoofdstuk dan ook weinig hoopvol met:

“In summary, ammonia may not be completely out of the game as a possible solution of the faint young Sun problem after all, although potential problems with the haze shielding and the high solubility of ammonia appear to make methane (CH4) and carbon dioxide (CO2) more likely candidates.”
Maar ook bij deze broeikas-gassen lijken er theoretisch nog al wat problemen op te lossen:
“Given the problems with ammonia as a greenhouse gas in the Archean, some researchers turned to methane (CH4) as a potential warming agent for the Archean climate. The main advantage of methane as compared to ammonia discussed in Section 5.1 above is that CH4 is photolyzed considerably slower than NH3, because it requires ultraviolet light of much shorter wavelengths (. 145 nm) where the Sun emits less radiation.
In the literature, estimates for Archean methane fluxes are often compared to this present-day flux (frequently and inaccurately even called the “current biological flux”). This is of course a valid order-of-magnitude comparison in principle, but it should be kept in mind that more than 60% of today’s methane flux is from anthropogenic sources (including industrial processes and emissions related to fossil fuels), and about 90% of the remaining natural flux originates from ecosystems which were not present during the Archean, i.e., wetlands, termites, wild animals and wildfires [Denman et al., 2007]…
Nevertheless, from these arguments one can conclude that methane mixing ratios in the Archean atmosphere of up to 1000 ppmv appear plausible (…) Comparing this to the results from climate model simulations for the late Archean (…), it is obvious that these are insufficient to provide enough warming given the paleosol constraints on carbon dioxide partial pressures during that time. Even if higher methane fluxes should have been achieved, haze formation limits the warming in a late-Archean methane greenhouse, although this depends on the details of organic-haze formation and the properties of the particles within the haze layer, see the discussion above.”
Voor methaan besluit Feulner echter ook weinig hoopvol met:
“In summary, it remains unclear whether methane could have provided sufficient warming at least for the late Archean, but a solution of the faint young Sun problem based on methane certainly appears to be considerably more complicated than previously thought.”
Dit is overigens in lijn met het bovengenoemde artikel van Rossing et al. (2011).
Maar voor deze theorie lijkt ook kooldioxide af te vallen:
“Despite the uncertainties discussed above, geochemical data therefore suggest that CO2 partial pressures were likely smaller than a few hundred times pre-industrial levels in the late Archean and early Proterozoic, meaning that carbon dioxide alone would most likely have been unable to provide enough warming during these times…
A further complication arises from uncertainties in radiative transfer calculations for atmospheres rich in carbon dioxide [Halevy et al., 2009; Wordsworth et al.,2010].
The problem arises because the wings of absorption line profiles and the parameters governing the continuum absorption of CO2 are poorly constrained by empirical data for the high CO2 partial pressures used in calculations of the faint young Sun problem. Wordsworth et al. [2010], for example, suggest that the radiative transfer calculations used in many earlier studies overestimate the CO2 absorption in the early atmosphere when compared to a parametrization which most accurately reflects presently available data.
It therefore remains to be seen whether carbon dioxide concentrations in agreement with geochemical evidence are sufficient to offset the faint young Sun.”

Ook onder de andere broeikasgassen heeft zich volgens Feulner ook nog niet een bijzonder waarschijnlijke kandidaat gemeld. Ethaan (C2H6), stikstofoxiden en carbonylsulfide vallen allen om verschillende redenen af. Ook de studie van Goldblatt naar een mogelijk versterkende invloed van

hogere gehalten stikstof in de atmosfeer, waardoor de absorptiebanden verbreed worden biedt onvoldoende soelaas:
“model calculations show that it could cause a warming by 4.4◦C for a doubling of the N2 concentration [Goldblattet al., 2009]. Nitrogen outgassed quickly on early Earth, so the atmospheric nitrogen content likely equaled at least the present-day value. Since all nitrogen in the mantle today must have been processed through the atmosphere, the reservoirs in the crust and mantle appear sufficiently large to explain higher atmospheric concentrations and thus a warmer Archean [Goldblatt et al., 2009].”

Feulner concludeert ten aanzien van deze studies:
“In summary, an enhanced greenhouse effect arguably still seems the most likely solution to the faint young Sun problem. Carbon dioxide and methane are the most obvious candidates, although they could face severe difficulties in terms of geochemical constraints and low production rates, respectively, and their respective contribution remains uncertain. Ammonia appears less likely than CO2 and CH4 because it would have to be shielded against photodissociation by ultraviolet radiation and because it would be washed out by rain…
After four decades of research the faint young Sun problem indeed “refuses to go away” [Kasting, 2010]. To a large extent, this is certainly due to the still limited knowledge of the conditions on early Earth, although the last decades have seen considerable progress, and some parameters are now better constrained than they used to be in the past…
Given the continued interest this important topic enjoys, the next decade might bring us closer to finally answering the question of how water on early Earth could have remained liquid under a faint young Sun, certainly one of the most fundamental questions in paleoclimatology.”