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Discussions

Interactive comment on "The regulation of the air: a hypothesis" *by* E. G. Nisbet et al.

Anonymous Referee #1

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This is a fascinating and ambitious ms, aimed squarely at one of the most fundamental and important mechanisms in the Earth System – that is, the maintenance of an atmospheric composition, throughout something over four billion years, that can in turn keep surface temperature in the range that will allow carbon-based life to exist – and more, keep it to an 'optimum' setting. The dominant hypothesis currently seems to be silicate weathering – and thus generally an inorganic one. This paper proposes that the Earth's biota essentially provide the control, through the action of an enzyme, rubisco (present in chloroplasts, and considered the most abundant protein on Earth) that regulates the fixation of carbon dioxide in photosynthesis, working in tandem with the enzyme nitrogenase, the enzyme that accomplishes, in some organisms, the difficult task of breaking the triple bond in dinitrogen to make biologically necessary nitrogen-based compounds.

The ms takes the long-known, and rather puzzling observation that rubisco seems

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to be an enzyme that has a remarkably sluggish activity – and also is remarkably 'wasteful' in that, at the active cite of CO_2 fixing, O_2 competes with CO_2. Thus, while it is relatively easy for CO_2 to get into a cell, once it is there it is not so easy to convert it into carbohydrate. The authors suggest that this situation isn't some unfortunate accident of the evolution of biochemical systems, a preserved atavism as it were, but has evolved via feedback systems that have acted to keep atmospheric CO_2 levels, temperature, and photosynthesis/plant growth mutually at optimum levels (to be "near-perfectly tuned").

Or so I understand it. If this is true – or if it is a significant part of the truth – then it is a very important insight into how the Earth has remained habitable for so very long. This paper is certainly worth publishing, and should hopefully spark off wide debate and perhaps even some deeper enquiry. I have a few general observations, though, which the authors might consider.

- Firstly, to get across to the wide audience it deserves, I think (writing as an unreconstructed geologist of the old school who is very much treading on unfamiliar and often baffling territory here), the argument and the mechanism should be spelled out more fully. The ms is written concisely and very elegantly – no problem there at all! – but it is written by scientists who have long acquaintance with, and deep understanding of, these complex biochemical mechanisms, and much of the potentially interested audience will have a far hazier grasp of these things. In section 2 (in particular) – if rubisco goes for oxygen instead of carbon dioxide, does it cause respiration? – or something else? And quite what is "CO_2/O_2 specificity" should be spelt out the first time the phrase is used, rather than a little lower. And I was lost in the arguments over whether the oxygen compensation point should involve one or two distinct functions, and remained hazy of what a plant specificity factor was, and in what units it might be measured.

Some revision of the ms along these lines (the authors are among the few people who combine the knowledge and explanatory powers to do this) would make this paper exceedingly valuable in helping to bring these ideas into the geological mainstream. Multidisciplinarity isn't easy – and those who try to swim in those waters (and are fated to be always out of their depth) do need a little help. . .

- Secondly, this idea of the dominance of 'plant-atmosphere-climate feedbacks' seems to me to be related to the Gaia hypothesis – a hypothesis that is not mentioned (and Lovelock is not quoted or cited). Association with the Gaia concept isn't always helpful to having ideas taken seriously in some circles, I know, but here I think some discussion would be useful, if only to provide reasons for dismissing it as a parallel.

In particular, the Lovelock's use of the Daisyworld idea (and its variant involving DMS) seems akin to the kind of regulation mechanism that would be needed in the case of rubisco: thus, a clear and vivid expression of a 'safety valve' for the Earth's surface heating controls.

- Regardless of the Gaia parallel, this is something that could be more explicitly developed in the ms. Generally, one assumes that too many plants with too-efficient rubisco (allied to some means of long-term carbon storage) would pull too much carbon out of the atmosphere, and this would lead to glaciation and consequently a thin time for plants generally. Recovery via rubisco would presumably (if I understand the argument correctly) tune this enzyme to a generally more sluggish state, leading to less photosynthetic drawdown and eventual warming. Only. . . for any individual plant in low-carbon conditions it surely makes sense to super-charge its rubisco yet further, to grab what little carbon is left out there as gas? A 'tragedy of the commons' scenario presumably holds for plants (and microbes) as well as for people – so how would it be overridden to collectively attain more or less 'ideal' conditions of carbon drawdown?

- The rubisco model generally (I'm still a little hazy on the detail) helps explain the long-term reduction in carbon dioxide as the sun has warmed. Its relation to the ups and downs of CO_2 through geological time may need a little more discussion, though, though some of these changes (e.g. Snowball Earth, and the glacial/Interglacial

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changes of the Quaternary, are briefly mentioned. For instance, the increasingly well-constrained drop in carbon dioxide at the Eocene/Oligocene transition (most lately ascribed to tropical weathering of an enormous obducted slab of oceanic crust) represented a long-lasting threshold between the high-CO2 world of the Mesozoic Greenhouse to the low-CO2 mid/late Cenozoic Icehouse. Why does not the (rapidly responding) rubisco feedback mechanism not work to even out these differences (as it is suggested that it did to even shorter-term perturbations such as volcanic eruptions)?

One factor here might be the balance not only between photosynthetic carbon fixation and respirative decay, but also variations in the long-term burial of carbon, that seems to be not so much under biological control, as a product of major tectonic and other patterns. Thus, the profuse plant growth of the Carboniferous would not have triggered the Permo-Carboniferous glaciation had it not been associated with a quite enormous subsiding delta system – a geological accident. And, the ups and downs of the Early Palaeozoic Icehouse might be reasonably, if provisionally, explained by Alex Page et al's (2007) oxic/anoxic 'carbon thermostat', with carbon burial on anoxic sea floors at times of glacioeustatic highs helping to drive down atmospheric CO2 (and vice versa) – this seems more a feature of oceanography than biology per se. The Quaternary glacial/interglacial transitions too, seem to be now explainable by alternating storage and release of a large volume of CO2 from the ocean depths.

Thus, the interaction of the biological mechanism with these other mechanisms (not to mention silicate weathering) seems to need more discussion, not least to more clearly disentangle the proposed biological mechanism from the various factors that acted to modulate it.

Interactive comment on Solid Earth Discuss., 3, 769, 2011.