Biogeosciences Discuss., 11, C3686–C3692, 2014
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Biogeosciences
Discussions
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Interactive comment on "The Habitable Zone of Inhabited Planets" *by* J. I. Zuluaga Callejas et al.

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Received and published: 23 July 2014

The manuscript discusses how life may influence its environment not only on Earth but on inhabited planets in general, based on what we know of general properties of life and how life on Earth changes the environment. Transferring our knowledge to inhabited terrestrial planets leads to a different (possibly larger) habitable zone than estimated in the classical habitable zone model of Kasting and others. The paper brings together first ideas from literature concerning how the habitable zone would change, based for example on the Daisyworld model by Lovelock and others.

While the topic as well as the conclusions of the paper are highly interesting to the community (even though not entirely new), especially concerning the habitable-exoplanet hunt, the paper lacks some critical points, which are listed below and need to be discussed more clearly. A major revision (of arguments and presentation in the paper, but not of the model or general idea of the study) is therefore suggested.

General points:

1. Two examples have been listed in section 4 discussing how life may acutally influence the width of the habitable zone (i.e. leading to the InHZ) - based on cloud formation and the Daisyworld. This section is the heart of the paper (leading to the conclusion that the InHZ is indeed larger than the AHZ), but both examples are somewhat immature (see next two points), and it is not clear at the end what are exactly the biological influences that lead to the larger InHZs depicted in Fig. 5. What exactly are the single effects leading to different inner or outer boundaries in the figure? It should be discussed in a clear way what are the specific pros of life at the boundaries of the HZ...

2. Sect. 4.1: To obtain the maximal possible cooling for a planet, the most favourable situation is a planet covered by low-altitude clouds on the day-side and no clouds at all at the night-side. In the paper it is assumed that life may lead to this very specific configuration. Even though life may enhance the cloud formation process, it is unclear

    - why life should only affect low-altitude clouds
    - why in this model no clouds are found at the night side (whereas they can be found on an abiotic planet)
    - if the model is possible in general (Is a large continent coverage allowed with deserts, which are likely not inhabited and therefore cloud-free?)
    - why the same clouds would not appear on an inhabited planet -> the planet is closer to its host star and oceans should vapourize more easily than on Earth, leading to a similar cloud coverage at the day side as here assumed as an effect of life

3. Sect. 4.2: The model (Eq. 1) strongly depends on the cloud coverage. A planet

covered by 100% clouds (or just 50% clouds at the day-side as in the first example) would be independent of any daisies.

How does the model look like at the boundaries of the InHZ? Would the inner boundary depend on the daisies, at all? Or would the optimal model include a 100% cloud coverage due to stronger evaporization of surface water? Then the inner boundary of the InHZ should be the same as for the AHZ.

For the outer boundary of the HZ, the classical HZ typically assumes a 100% CO_2-cloud coverage to have a maximum heating effect. The surface albedo would therefore not matter in the InHZ model and the boundaries should be the same...

The mortality rate is constant here, but shouldn't it also depend on temperature etc. as the growth rate? How large are the surface coverages a_w and a_b at the inner or outer boundary of the InHZ? I would expect them to be rather low at extreme temperatures, which would mean that the effect the daisies have on the inner/outer boundary are rather small and the InHZ would be again close to the AHZ.

4. This is a rather minor point, but I have to say that I personally don't like the name abtiotic HZ (AHZ). It stands for the classical HZ model, where the Earth-like carbon-silicate cycle is included. Kasting himself states in his 1993 paper in his conclusions: "Planetary habitability is critically dependent on atmospheric CO_2 and its control by the carbonate-silicate cycle". The CSC on the other hand strongly depends on the Earth's biota (as you mention also on p. 8448, l. 8-10), the AHZ therefore has an indirect life connection (the CSC also needs continents/plate tectonics, water, etc.). In other words, if Kasting et al. would indeed use an abiotic world, the HZ would be much, much narrower than the one they use for Earth with a let's say fixed life influence. It would be, however, interesting

BGD
11, C3686–C3692, 2014

to compare a pure abiotic HZ with the Earth-like, classical HZ and your biotic InHZ.

5. The question of why the InHZ may be important and why the search for exoplanets should not be limited to AHZ-planets is poorly addressed so far. The argument p.8449, lines 3-12 is in my view not acceptable. The origin of water does not need specific explaining because there are several ways to obtain water at the surface of a planet (condensation of preliminary atmosphere, outgassing, comets etc.). The question is if water can stay at the surface or if it freezes/evaporizes/is lost to space. For life, this is different. A planet will start uninhabited, and to allow for the origin of life, specific conditions need to be met (temperature, water, nutrients). However, the InHZ is quite interesting if a planet is not in the AHZ but locally habitable (habitability niches like suggested on Mars, volcanos that lead to local surface temperature above freezing point, ...). If life origins there and changes the atmospheric environment, global habitability might be given later (and the planet would be in the InHZ but not in the AHZ). Second, if a planet was in the ABZ at an earlier time (and life may have formed there already), and the HZ shifts away from the star with time, the planet may stay habitable due to life influences but would not be in the AHZ anymore (like in Fig. 1). These two arguments justify that there may be inhabited planets outside of the AHZ on both sides.

Minor points:

1. p. 8446, l. 11 and p. 8448, l. 27: The paper by Rosing et al. 2006 (The rise of continents - An essay on the geologic consequences of photosynthesis, Palaeogeography, Palaeoclimatology, Palaeoecology 232 (2006) 99 - 113) could be mentioned here as well.

2. p. 8447, l. 6-7: Mars and Venus are used as limits for the HZ? Really? I thought that they are by chance at the boundaries of the RHZ, but that the limits are actu-

BGD
11, C3686–C3692, 2014

Interactive Comment

ally determined for an Earth-like planet that adapts to the inner/outer boundary? But I might be wrong here...

3. p. 8447, l. 27: Why "abiotic"? It sounds a little bit strange, that life interacts with the abiotic planetary environment, after some time the enviroment would not be abiotic anymore, and hence the InHZ is different from the AHZ...

4. p. 8452, l. 15-16: The statement that defining the InHZ brings the revolution is a little bit, well, over-optimistic. One may also argue that the DW model and other studies related to widening the HZ already brought this revolution...

5. p. 8453, l. 22-28: The possibility of destabilizing organisms is quite interesting. One may even argue that if these organisms would destabilize a world and start to push the environment into a runaway-direction, that due to the fast changes of the environment the mortality rate should immensly increase, leading to less biota and hence less destabilization...

6. p. 8462, l. 9ff: here a_b and a_w are defined, but not used in the following equation, which is irritating. I would include an equation at that point showing how the surface albedo depends on the fractions of white daisies, black daisies and bare-ground, instead of mentioning it later in lines 17-19.

7. p. 8464, l. 23: do you mean "dry dead" instead of "wet dry"?

8. p. 8468, l. 15ff: what is meant here by unregulated? Not even physical/chemical regulations of an abiotic world? Or was this calculated for an abiotic planet? But then, no AHZ would exist, at all...
   This argument here seems to be very strange, and the conclusion, that water may be a biosignature, even stranger. Earth's oceans were just fine during the first 2 billion years of Earth when no or almost no biomass yet existed on Earth...

BGD
11, C3686–C3692, 2014
Interactive Comment

9. p. 8468-9, l. 26-4: sorry, but I couldn't follow your arguments here. What is the difference between your concept and the Gaia/BR concepts? Do they say that life is the most important factor or would you say that? As far as I always interpreted the Gaia system, life cannot regulate everything, so if you take away one important chain, the whole system breaks down. This is also what you say, correct?

10. p. 8469, l. 10: well, you are looking for inhabited planets and not directly for a second Earth, I would say...

11. p. 8469, l. 18-19: I would say "the only inhabited planet we know so far", people argue about habitable niches on Mars, for example, and several planet candidates have been detected in the AHZ so far...

12. Fig. 1: Plots 4 and 5 in the right column: shouldn't the temperature (for U) increase here with time?

13. Fig. 5: It would be interesting to add here three dots for Venus, Earth and Mars as reference...

14. There are some spelling and grammar errors, some that I found while reading the text are listed below:

    - p. 8444, l. 4: This hypothesis lead***s***
    - p. 8445, l. 6: has nowadays reach***ed***
    - p. 8445, l. 13: a planet receive***d***
    - p. 8445, l. 19: provided the planet ha***s***
    - p. 8445, l. 25: The definition ***of*** the HZ
    - p. 8446, l. 8: the estimation ***of*** the limits
    - p. 8446, l. 18: Höning et al. (2013) ha***ve***

BGD

11, C3686–C3692, 2014

Interactive Comment

- p. 8447, l. 7: we show, throug***h c***onceptual experiments
- p. 8447, l. 22/23: InHZ as o***ppos***ed t***o t***he AHZ
- p. 8456, l. 25: higher ***than*** the
- p. 8459, l. 16: very ***often*** gives rise
- p. 8464, l. 4: Clouds influenc***e*** also
- p. 8466, l. 19: have es***ta***blished
- p. 8467, l. 27: actually exist***s*** on
- p. 8468, l. 13: ha***s*** a larger albedo
- p. 8469, l. 18: idea that life ha***s***
- p. 8469, l. 21: shown t***hr***ough

Interactive comment on Biogeosciences Discuss., 11, 8443, 2014.