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Reply on RC1

Oliver López-Corona et al.

Author comment on "ESD Ideas: Planetary Antifragility: A new dimension in the definition of the Safe Operating Space for Humanity" by Oliver López-Corona et al., Earth Syst. Dynam. Discuss., <https://doi.org/10.5194/esd-2021-26-AC4>, 2021

Dear Professor Karo Michaelian (KM),

Thank you very much for the encouraging, critical and insightful review comments, your recommendations and questions will considerably improve the quality and clarity of the manuscript. In order to do this, we have invited Professor Jon Lovett to enrich the interpretation, ecological background and general writing quality. Please find below the detailed answers to each of the questions and concerns.

KM: This is an interesting article using planetary albedo as a proxy for photon dissipation (or entropy production) to make an analysis of the time variability of the biosphere response due to, ostensibly, changing of planetary habitats by humans. I want to encourage the authors in their work since the manuscript provides a unique and more global way at looking at the whole question of ecosystem stability, fragility, resilience, etc. by considering all its interconnections in a global measure of entropy production, giving rise to, for example, homeostasis.

Response: We are glad that the spirit of the article, main purpose and contribution is clear enough and thank you for the encouraging words.

KM: However, the manuscript must be written much more carefully, respecting all the etiquette of good writing. The manuscript is difficult to read in parts as a result of poor attention to detail and because the English is lacking.

Response: We acknowledge that to communicate efficiently what we consider a novel and potentially unifying idea for establishing a measure for x , y and z , the revised manuscript will undergo a detailed writing revision. Manuscript revision will consider all the concerns, which you have pointed out, such as improving the abstract; consider all the particular comments; an extension on the relation between antifragility and Fisher Information; definition of all symbols in equations; re writing of paragraph on line 71 among others; Reference consistency and style.

In general, we emphasized the possibility of measuring global antifragility using systemic planetary variables and the difficulty of identifying them and their availability for time series analysis. By explaining the restrictions about suitable and available data sets to explore the theoretically proposed thermodynamic function of ecosystems, we made clear

why our proposal could be considered as a unique proposal and why it could be seen as an advancement of the existing theoretical framework.

KM: Line 12; ... humanity would operate safely..." to "humanity could operate safely..."

Response: Done

14; "Despite PB has been widely accepted,..." change to "Despite the concept of PB being widely accepted,..."

Response: Done

14; "Although the authors recognize..." change to "Although Rockstrom et al. recognize..."

Response: Done

16; "Then it would be necessarily to have ..." to "Then it would be necessary to have ..."

Response: Done

16; "Planetary Limits (LP)" to "Planetary Limits (PL)"

Response: Done

18; "the authors say" to "Rockstrom et al. say"

Response: Done

21; "Rockström and co-workers does recognise" to "Rockström and co-workers recognize"

Response: Done

The concept of "antifragility" should be more carefully defined and its relation to "Fisher Information" better explained.

Response: Done

62; All symbols in Eqs. (3) and (4) should be defined.

Response: Done

71; The paragraph beginning on line 71 should be re-written as it is difficult to make sense out of.

Response: Done

82; Include a reference in figure 1. The wavelength region used to determine the albedo should also be listed.

Response: Done

90; The variable " τ " does not appear in the equation. More information should be given as to how the Fisher Information for albedo was determined.

Response: Done

165; The References lack a consistent format and should be cleaned up.

Response: Done

KM: Some questions I was left with concerning the analysis, whose answers would increase the value of the manuscript, are;

1) Is ocean surface albedo included in the data? If so, could this be dependent on periodic global events such as El Niño?

Response:

The different albedo products derived from satellite imagery in general are processed only for terrestrial surfaces because ocean albedo is rather stable and low which may produce that higher fluctuations get masked/averaged by ocean albedo, and thus the original input does not include ocean surface albedo. So, the influence of periodic phenomena like El Niño Southern Oscillation (ENSO) could not affect the results because of change in ocean surface albedo. But it must be considered that land cover, which influences terrestrial albedo to a large extent, is heavily influenced by the teleconnections caused by "spatially and temporally large-scale anomalies that influence the variability of the atmospheric circulation" (ENSO, Arctic Oscillation, North Atlantic Oscillation, Pacific Decadal Oscillation, Pacific-North America Index (<https://www.ncdc.noaa.gov/teleconnections/>)). This leads to climate anomalies linked across geographically separated regions. This leads to bigger or smaller changes in land cover type (e.g. arid environments with abrupt growth of annual plants after anormal precipitation or drought related phenotypical changes in normally humid areas).

Another interpretation related to this cyclical pattern could be based on critical slowing down: Strogatz 1994 proposed critical slowing down as representing the major contribution from the authors. Critical slowing down "implies that recovery upon small perturbations becomes slower as a system approaches a tipping point" (Scheffer et al. 2015). This could explain why the recovery after the first cycle of loss of Fisher information does not reach the original value, as a slowing down means less recovery in the same amount of time. If the time of recovery and loss of Fisher information is determined by oscillating climate phenomena, a slowing down of recovery would mean less recovery between cycles.

2) It would be nice to see the results for both the northern and southern hemispheres, alone and together, could this be done?

Response: As far as we understand it would be possible but we do not think that it is necessary for making a proof of concept analysis as the one we present here in the context of the type of paper, so we consider it is a clear next step analysis for a following paper

3) What are some of the problems that could arise by using visible albedo as a proxy for global entropy production?

Response:

In human health assessment the first order approximation has been identified with the previously known reference range of value of some key physiological variables such as heart rate and systolic blood pressure. So one problem with using visible albedo as a proxy for global entropy production is we do not have the equivalent of those reference values, which in this case should be determined for each ecosystem type. In that sense, visible albedo should be applied in a spatially explicit way, not averaging mean values

over large regions, but using local values because the values need to be evaluated in reference to the correct reference values.

Another problem would be considering visible albedo values without their dynamics, as can be illustrated with an analogy to human health: Consider a person with a broken arm (unhealthy state) but healthy heart (healthy dynamics) versus an olympic athlete (healthy state) but with a condition prone to sudden cardiac syndrome (unhealthy dynamics)

Given these two considerations, we decided not to rely on the direct value of albedo but rather its Fisher information, which encodes the system's dynamics in terms of its capacity to respond to perturbations.

Other problems could be that the real extent of the ecosystem considered in the measurement depends on the height of the remote sensor because of the relation with the solid angle of the detector.

Finally, an albedo value is an "instant" measurement and it could be necessary to integrate measurements across a 24h cycle (don't know if that is even possible) or other longer cycles; but perhaps this is not important for a long term analysis, as presented in this work. Nevertheless, it does point to the fact that this work does not present a fully developed framework for Planetary Antifragility, we still need to resolve if remote sensing measurements of Albedo really can capture sufficiently well entropy production or if other signals should be needed which most likely would be the case in a more detailed scale, for example a particular ecosystem in a concrete region.

As the type of publication indicates, this is a first illustration of the general idea of using antifragility as a new dimension in the definition of the Safe Operating Space for Humanity and after discussing some aspects of the advantages and problems with using albedo measurements derived from satellite imagery in this manuscript, we would very much like to further explore other variables that could be used to construct indicators for planetary antifragility. In addition to albedo, we think it would be very interesting to incorporate the biocustic signal and maybe also the ecosystem respiration. Every sound emitted by a living agent in an ecosystem somehow is coding part of the ecosystem metabolism into a signal. Also important biocustic are produced by members of the Animalia kingdom and would prevent the problem posed by defaunated ecosystems which from a plant perspective could seem to be healthy (in the short run) . For its part, ecosystem respiration include soil respiration and soil is a complex system that incorporates all spheres (biosphere, geosphere, atmosphere, hydrosphere), several biogeochemical processes, many spatial and time scales, so it conjugate many sources of information about the ecosystem. These other signals were not considered for a Planetary scale because data are non-existent.

4) Is there an explanation as to why the Fisher Information appears to go down and then up and down over time?

Response:

Considering response 1), we propose that the observed results could be interpreted as a cyclical decrease in Fisher information, as the increase after the completion of one cycle does not rebound to the original value but stays below. This decrease would be associated with a loss of stability (degradation?) overlapped with oscillations caused by changes in terrestrial albedo as a response to teleconnected climate oscillations.

If we consider that human activities affect land cover on most of the earth's surface directly by land use and indirectly by climate change related differences in the teleconnected phenomena, we could suspect that the cyclical degradation of the observed

system could be anthropogenic and related to several planetary boundaries (see explanation of teleconnections and land cover land use complex to infer major ecosystem services that are influenced).