ESD Ideas: Planetary Antifragility: A new dimension in the definition of the Safe Operating Space for Humanity

Major revision, Response to the editor.

October 12, 2021

Dear editor,

Thank you very much for all your work.

We are greatly satisfied by ESD open review system and think the discussion stage was of great value thanks to reviewers' insightful comments. We are presenting a merged version of our responses to reviewers, which we incorporated in this revised version of the manuscript.

Best regards

Oliver López-Corona

Earth System Dynamics Discussions

Earth Syst. Dynam. Discuss., author comment AC4
https://doi.org/10.5194/esd-2021-26-AC4, 2021

Reply on RC1

Oliver López-Corona and Melanie Kolb

Author comment on "ESD Ideas: Planetary Antifragility: A new dimension in the definition of the Safe Operating Space for Humanity" by Oliver López-Corona and Melanie Kolb, 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 "\tau" 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 de signal. Also important bioccustic 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).

Earth System Dynamics Discussions

Earth Syst. Dynam. Discuss., referee comment RC3
https://doi.org/10.5194/esd-2021-26-RC3, 2021

Comment on esd-2021-26

Anonymous Referee #2

Referee comment on "ESD Ideas: Planetary Antifragility: A new dimension in the definition of the Safe Operating Space for Humanity" by Oliver López-Corona and Melanie Kolb, Earth Syst. Dynam. Discuss., https://doi.org/10.5194/esd-2021-26-RC3, 2021

Does the paper address relevant scientific questions within the scope of ESD?

This paper addresses relevant scientific questions within the scope of ESD, and it is a vanguard study that aims to explore new scientific perspectives more than presents finish results. With an interdisciplinary approach, this article integrates knowledge and methods from different disciplines to create a unity of intellectual frameworks beyond the disciplinary perspectives. More than analysing technical content, this approach is highly pertinent because it uses photon dissipation as a proxy to understand how Safe Operating Space for Humanity is being modelled, and why these models need to evolve. Through planetary albedo, it understands and critically identifies several problems in state values of Planetary Boundaries. More than physics and geosciences, it is possible to understand how socio-natural systems are connected and how the current epistemological approach globally affects ecosystem stability, fragility, and resilience.

Does the paper present novel concepts, ideas, tools, or data?

The paper presents new data about changes of shortwave global albedo anomalies to introduce planetary antifragility as a fundamental concept in the time variability of the biosphere response due to human action. It uses the dynamic interpretation of Fisher Information Theory as a tool to support new interpretations and conclusions about the necessity of updated ideas from old paradigms. The title clearly reflects the components of the paper and abstract, which is concise and complete.

Are substantial conclusions reached?

Substantial conclusions are reached. With the Cybernetic Revolution and anticipating the current crisis of truth, Information Theory rescues (from the Greco-Roman) the importance of entropy in science as well as the organised development of the complexity sciences, absent from the epistemological discussions and philosophy of the sciences, by centuries. With scientific methods and assumption valid and clearly outlined, this paper shows that Planetary Boundaries are not interdependent. Individual Planetary Limits do not establish proper threshold configuration. That is why it is necessary to have a metric of the interaction.

There is no such thing as the certainty of transgressing a defined tipping point and an

incompatible human survival certainty. Ideas are conveyed and substantiated, as in the philosophical, conceptual, and organisational issues. In addition to the technical part, there is a whole part of fundamental science - the structure of thought and credibility. Authors analyse with new data and scientific methods that the concept of resilience is a particular and limited case of Antifragility.

Concluding that Safe Operating Space for Humanity should also include planetary Antifragility is a tremendous act of bravery of the authors. Ironically, living in a society where entropy measures are omitted in the communication of changes and modelling of systems is equivalent to construction where there is also no freedom - in scientific, social and political structures. Since grounding scientific certainty is an age-old failure, logic points to the disruption and collapse of its own civilisational system as inevitable.

More than representing a physical phenomenon, it is crucial to see in the exact and physical sciences the possibility of representing social models and applying exact and physical science methodologies to objects formerly exclusive to the social sciences. Avoiding the moralisation of science, true or false are just qualities of language and not things. Without language, there is neither truth nor lies (Thomas Hobbes, Leviathan, 1651). This paper presents a unique way of understanding the whole question of ecosystems and society by considering all its interconnections (stability, fragility, resilience, etc.) in a global measure of entropy production, giving rise to, for example, homeostasis. Like António Damasio or Edgar Mourin say, cell biology shows us that the cell dies due to incapacity for homeostasis when this happens.

Are the scientific methods and assumptions are valid and clearly outlined?

To analyse if scientific methods and assumptions are valid and clearly outlined is essential to understand that developing something unknown in the borderline between the known and the unknown has consequences. Frontier investigations address issues about which there is intense controversy in the scientific community in the field in which they are developed. They work with difficult questions, at least with mainstream methodological approaches, and they use methodologies and concepts atypical in their area. This kind of research implies starting from unexpected results that question the dominant paradigm and highlight issues whose solution is fundamental to confirm (or refute) the current paradigm. Investigations have a very high level of uncertainty about their success, but they nurture a high potential for transformation and renewal of knowledge.

Are the results sufficient to support the interpretations and conclusions?

This paper concludes that components of planetary boundaries are not interdependent, and the interaction among them matters. There is a perturbation response in the capacity dimension, and it is necessary to underly the Antifragility framework in systems dynamics measure of this perturbation response capacity. The net reduction of 47.63% loss in Antifragility is a satisfactory result to support interpretations and conclusions of this compounding problem (human perturbations vs planet capacity to respond to them) about core biogeochemical processes with Planetary Boundaries.

Humanity has become an active agent in shaping physical climates worldwide through cultural, social, political and ethical practices that reinterpret what "climate change" or other "geophysical processes changing" means. Modernity has always kept the discussion of entropy and complexity absent from epistemological discussions and science philosophy. The dream of turning scientific theories into axioms and giving them an absolute rationale was lived.

The discussion of certainty/entropy in science and the demarcation between science and non-science considered philosophy an empty discourse (Hilbert, Popper, Kuhn, Feyrabend

or Lakanos). However, after years of research, Popper concluded that the concept of science is no longer synonymous with certainty. Actually, it becomes synonymous with uncertainty, or rather, reliability (a measure of entropy). Regarding the discussions on the classification criteria of what science is, Popper (1963) concluded that a theory that is not refutable by any event, whatever it may be, is devoid of a scientific character. Nine years later, he said that science is a method of bold conjectures and ingenious and severe attempts to refute them. This paper is a precious example of science in his terms.

Is the description of experiments and calculations sufficiently complete and precise to allow their reproduction by fellow scientists (traceability of results)?

Regarding traceability of results, this manuscript's most important contribution is not about allowing the reproduction by fellow scientists about absolute, precisely and sufficiently complete descriptions of experiments and calculations. Within the scope of ESD, experiments and calculations of this paper contribute to the traceability of ideas. The most important result is the "ideas" and not precise quantitative numbers. The authors guarantee the traceability of results: 1) representing natural, technical and social phenomena as complex coevolutionary systems, using mathematical formulation to systematise their interdisciplinary and dynamic structure, as well as spatiotemporal interaction; 2) promote and understanding of the dynamics of emerging, transitional and extreme regimes, together with the associated entropy and evolutionary predictability - frame the changing core biogeochemical processes with Planetary Boundaries and Safe Operating Space for Humanity. 3) Develop learning techniques for Machine Learning and Artificial Intelligence for interdisciplinary analysis and model design beyond the mechanistic paradigm, 4) Using mathematical methods to improve dynamic decision support structures, incorporating natural, social and technical risks.

Do the authors give proper credit to related work and clearly indicate their own new/original contribution? Are the number and quality of references appropriate? Is the amount and quality of supplementary material appropriate?

Frontier Science has difficulties in penetrating the scientific community, whether through dissemination in the form of publications or communications, and, for the same reasons, has challenges in finding funding. As exciting and attractive as IDEAS are, creative and innovative potential researchers have, life in frontier science is not a path that most scientists can choose. The authors give proper credit to related work and clearly indicate their own new/original contribution. The number and quality of references and quality of supplementary material are appropriate.

A precise consequence of the current paradigm, science promotion systems severely penalise the risk of failure, which adds to the intrinsic difficulty that accompanies frontier investigations. The intensity of this type's investigation is low compared to the mainstream (Kuhn's normal science). However, frontier science emerges in moments of crisis – Thomas Kuhn says. This paper is the perfect example. Suppose we want an authentic transformation of knowledge. In that case, it is necessary to promote cutting-edge research and recognise and foster the curious and critical spirit in academia and research centres. In addition to the excellent technical training provided by conventional science, new ideas and methodological and conceptual approaches must emerge from the academic world. Frontier Science can bring a future to the present, even when even those who practice it cannot anticipate it. An answer to the next question, the following unexpected result, the next innovative challenge, the knowledge that R&D systems and financing mechanisms can imagine.

That is why the scope of ESD is so essential, and papers like these are so crucial in academia and scientific society. This manuscript has interdisciplinarity, scientific merits, technical quality and suitability.

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Reply on RC3

Oliver López-Corona and Melanie Kolb

Author comment on "ESD Ideas: Planetary Antifragility: A new dimension in the definition of the Safe Operating Space for Humanity" by Oliver López-Corona and Melanie Kolb, Earth Syst. Dynam. Discuss., https://doi.org/10.5194/esd-2021-26-AC7, 2021

Dear reviewer,

thank you for your deep and thoughtful comments.

Novel work is always problematic and risky because it faces both genuine questions for which there may be no clear and consensus answers; but also faces cultural and field biases especially in interdisciplinary problems.

This is why we think your observation about what is the main result of the work is key. We are not by no means providing the ultimate, complete and undisputable data analysis. We are presenting a **new Idea** and some supporting preliminary analysis for showing it is scientifically sound and more important, to point the path that could be followed to subsequent development.

So it is important to remark for the community that ESD Ideas article type "presents innovative and well-founded scientific ideas in a concise way that have not been comprehensively explored. We are convinced that under these definitions our work does comply".

Also, an anecdote from Professor Enrique Hernández Lemus may help. Some years ago Prof. Lemus asked Professor Leopoldo García-Colín about publication types and how to know when an idea is ready to be published. García-Colín told him that When formal scientific publication began, with scientific societies such as the Royal Society and others like it, there were two kinds of "scientific articles": the 'proceedings' or 'transactions' and the 'letters'. Both were very relevant, he continues, but they served different purposes: "proceedings" were published every year or perhaps every two years (that is why the volumes that contained them were sometimes called "Annals", that is, they were yearbooks) to report the status of the research one was doing on a given topic or project. They were work reports, progress reports, and state-of-the-art updates. After a time, generally indefinite, one ended up discovering or finding something very relevant that should be made known to the scientific community. To communicate this discovery, one wrote a letter, usually brief (since the details of the daily work were already published in the previous proceedings).

The problem is that the modern academy has somehow lost this tradition, that we

consider code what in modern terms we recognize as the optimal search strategy in a complex environment (in this case the space of scientific ideas). As we know from ecological research, Lévy flights have been recognized as the optimal searching strategy to find scarce, randomly distributed resources (Viswanathan et al. 1999; Bartumeus et al. 2005, Boyer et.al. 2006). Levy flights consist of a regular random walk (local search) and from time to time very big displacements (the flights) that allow the agent to search in new regions of the resource space. Of course in the scientific context, most of the times papers need and naturally fall into this local exploration of scientific ideas. But if we take nature and its evolutionary processes as a role model for search resource space, we also need to accept "IDEAS" papers that put a new set of lenses on a particular field. After a flight, there is a clear necessity for local exploration and much work has to be done.

Earth System Dynamics Discussions

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Comment on esd-2021-26

Anonymous Referee #3

Referee comment on "ESD Ideas: Planetary Antifragility: A new dimension in the definition of the Safe Operating Space for Humanity" by Oliver López-Corona and Melanie Kolb, Earth Syst. Dynam. Discuss., https://doi.org/10.5194/esd-2021-26-RC4, 2021

The manuscript is very interesting and very new aspects of research on antifragility. The work is very impressive. However, due to the novelty of the work, it needs implicit pros and cons of the notion as well as previous studies. The objective of this study is not clear and the mathematical treatment lacks proper definitions. Moreover, it is not implicitly explained how Fisher Information is related to human operating space. For this, the authors shall demonstrate the physical meaning of such qualifiers and also align with the scope of ESD.

- There are some jargon need to be defined properly and hence hard to understand. For instance, the authors introduced "**TOA**" on line 80 for the first time. What it stands for? Give its full form. Likewise, the reviewer asks to define L_{rad}, $L_{in,}$ and λ implicitly in Equation 3 and other variables in Equation 4.
- On line 20, "of" is missing between work and Equihua et al.

Earth System Dynamics Discussions

Earth Syst. Dynam. Discuss., author comment AC9
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Reply on RC4

Oliver López-Corona and Melanie Kolb

Author comment on "ESD Ideas: Planetary Antifragility: A new dimension in the definition of the Safe Operating Space for Humanity" by Oliver López-Corona and Melanie Kolb, Earth Syst. Dynam. Discuss., https://doi.org/10.5194/esd-2021-26-AC9, 2021

Dear Reviewer,
thank you again for all your comments, we will consider them on the revised version of the manuscript to improve its quality, please see comments on your first post.

We now would like to kindly ask you to consider the following:

We know that the present work does not provide the ultimate, complete, and undisputable data analysis, nor a complete mathematical formulation; but this is this way because the main "result" as identified by Reviewer 1 is the new "Idea" presented. We include some supporting preliminary analysis was added to show it is scientifically sound and more important, to point the path that could be followed to subsequent development.

So it is important to remark that an ESD Ideas paper is intended to present innovative and well-founded scientific ideas in a concise way that have not been comprehensively explored.

We are convinced that under this definition our work does comply.