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Interactive comment on "A mathematical approach to understanding emergent constraints" *by* Femke J. M. M. Nijsse and Henk A. Dijkstra

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We thank the referee for the careful reading and the useful comments and will adapt the manuscript accordingly. Below is a point by point reply with the referee's comments first, followed by our reply and the changes in manuscript.

1. Comment of the referee: I see as main (yet minor) pitfalls of your paper the somewhat confused presentation in Section 2 and the fact that the classification of the emergent constraints is also a bit unclear.

Authors' response: We will aim to clarify both issues.

Changes in the text: Section 2 and 3 will be rewritten as to separate the more general derivation from the Ornstein-Uhlenbeck example. The classification of the emergent

constraints in section 3 will be made more clear as per the suggestions of the referee.

2. Comment of the referee: I think you should also discuss a bit more in detail the difference between considering multiple models, instead of one with parametric modulations.

Author's response: Suggestion followed.

Changes in the text: We will address the differences between the two cases (multiple models vs parameter variation in a single model) in the revised discussion section of the paper.

3. Comment of the referee: Additionally, you might find useful a recent preprint of mine: https://arxiv.org/abs/1806.03983 where I address the problem of looking at observables as predictands and predictors. This problem is (briefly) mentioned in your paper, but maybe my preprint can be useful for discussing your results.

Authors' response: We have read the paper and the material is indeed highly interesting and relevant for our paper.

Changes in the text: It will be used when rewriting part of section 3 on the classification of the emergent constraints.

4. Comment of the referee: Please also note the supplement to this comment: https://www.earth-syst-dynam-discuss.net/esd-2018-15/esd-2018-15-RC2- supplement.pdf

Authors' response: Many thanks for the very useful questions, remarks and suggestions for changes; they are discussed below.

Changes in the text: All these suggestions will be taken into account in the revised paper as per the point-by-point reply below.

5. Comment of the referee: Section 2: I think you should frame response theory in general terms, and then propose this (relevant and illustrative) example. Otherwise,

the reader can be a bit confused.

Authors' response: Good point. Now we only refer to the general theory of response theory in the introduction and discussion, but this is the most logical place.

Changes in the text: Section 2 will be rewritten to better separate the general results from that of the example.

6. Comment of the referee: I also think you should cite the Hairer and Majda 2010 paper regarding response theory for stochastic systems and the original Ruelle 1998, 2009 papers on response theory in a deterministic setting.

Authors' response: We indeed mainly referred to the book by Pavliotis, but it is indeed good to cite the papers in which these advancements were made.

Changes in the text: References to the papers by Ruelle (1998, 2009) and Hairer and Majda (2010) will be added.

7. Comment of the referee: Page 3, line 30 (in the version attached to review, which is the 2-column version of the ESDD paper): be more specific. Firstly, an emergent constraint can be either direct or indirect. In the direct case, the predictor and predictand are the same observable, while in the indirect case the predictor variable and predictand variable have to be linked via a physical process.

Authors' response: Indeed, it was not made explicit that indirect simply means not the same variable.

Changes in the text: The sentence will be changed to: Firstly, an emergent constraint can be either direct or indirect. In the direct case, the predictor and predictand are the same observable, while in they are not. In the latter case, the predictor variable and predictand variable have to be closely linked, for instance via a physical process.

8. Comment of the referee: Page 3, line 69: Do you mean: when taking ensemble averages?

Authors' response: Not when we talk about an ensemble generated by varying a parameter. For a linear relationship to appear (A = Cst B), the ratio of susceptibilities should be constant (A/B= Cst).

Changes in the text: We will write out that (A= Cst B) to show readers nothing special is going on here.

9. Comment of the referee: Page 3, line 79: The equation 3.2 is unclear

Authors' response: Indeed, the accompanying text was quite unclear.

Changes in the text: We will add: "One variable (B) can act as forcing to a second variable (O), while being itself forced by some external variable (F). Furthermore, often the forcing patterns are not exactly the same for the short and long periodic forcing, leading to:"

10. Comment of the referee: Page 4, line 7 Yes, but you have lost sensitivity on \gamma

Authors' response: This is the point. If there was still a dependence on gamma, no linear relationship would have appeared.

Changes in the text: By making equation 3.1 more clear, we will make this more apparent.

11. Comment of the referee: Page 4, line 18: This has to do in fact, with the sum rules and asymptotic properties studied in Lucarini and Sarno (2011).

Authors' response: Thanks for this remark, but it would be too much detailed to discuss that here.

Changes in the text: None.

12. Comment of the referee: Page 4, line 55: isn't this just a special case of 3.1, just with \omega_2=0?

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Authors' response: This is not a special case of equation 3.1. Here we are not interested in the response to forcing at all, only in the expectation value. This was explained in the text in the left column, but apparently not sufficiently clear.

Changes in the text: The difference between the low frequency limit $\omega_2 \to 0$ of (3.1) and equation (3.5) will be explained in the revised text.

13. Comment of the referee: Page 5, line 31. maybe it can be made a bit clearer?

Authors' response: The reason why was indeed omitted.

Changes in the text: The last sentence of this paragraph will be changed to clarify the role of the signal-to-noise ratio In finding an emergent constraint.

14. Comment of the referee: Page 7, line 15: As long as different models are closely related and structural differences can be approximately parameterized.

Authors' response: Agreed.

Changes in the text: This will be added to the revised text at the end of section 4 and also when discussing the cases (multiple models vs parameter variation in a single model) in the revised section 5.

15. Comment of the referee: Page 7, line 29: I believe that this specific classification should be better explained.

Authors' response: Agreed.

Changes in the text: This has been now made clearer in section 3 and will be repeated in the revised discussion section.