Response to the points raised by Reviewer 2

Thank you very much for your evaluation of the manuscript. Please find below the list of your points together with the answers (italicized).

Review of "Weather pattern dynamics over Western Europe under climate change: Predictability, Information Entropy and Production" by S. Vannitsem (Nonlinear Processes in Geophysics)

In this manuscript, the author analyzed the entropy and its production in the information theory to study the impact of climate change on the weather patterns over Western Europe. In historical data for the period 1885-2000, the author found a decreasing trend of the block entropy except afterward of 1980, which suggests a less diverse set of pairs of events. In addition, an increasing trend of the entropy production for 6 and 8 weather patterns indicates a time-asymmetry related to the irreversibility of the process. The analysis of the UK Met Office CMIP5 model showed a wide range of the block entropy evolution depending on the realization. These findings suggest that the degree of irreversibility is increasing under climate change.

The manuscript is well written with a clear structure. I believe this study would contribute to understand how climate change affects the weather pattern over Western Europe. In addition, the application of block entropy to climate model runs would be useful index to evaluate climate models. However, I have concerns due to the lack of the discussion that connects the obtained results and weather events.

Thank you very much for your positive evaluation of the manuscript and raising this important point on the link between the classical thermodynamic entropy and the information entropy production. We address your main point below.

Major comments:

Discussions that connect the (information) entropy production to atmospheric dynamics would be helpful to deepen our understanding of climate change impact on the weather regime. The authors wrote that the production of information entropy is related to irreversibility of the system, and its trend would be associated with the heat production/dissipation in the thermodynamic entropy. I wonder if the production of information entropy is associated with the irreversible processes in the large-scale atmospheric dynamics, like irreversible mixing of momentum that occurred at the Rossby wave breaking. Modulation of Rossby wave breaking is known to be associated with the transition of weather regime (Michel and Riviere, 2011).

The positive character of information entropy production is providing an important signature of a time asymmetry in the behavior of the system, in analogy with the thermodynamic entropy production (Gaspard, 2004; Nicolis and Nicolis, 2012). This time asymmetry is associated with an irreversible evolution, which again by analogy with the standard thermodynamic entropy, can be associated with the presence of dissipative processes and to global constrained driving the system out of equilibrium (Nicolis and Nicolis, 2012). The precise link between the information entropy production, thermodynamic entropy production, and dissipation is however a complicate question. It has already been successfully addressed at the microscopic level by a certain number of authors *(e.g. Roldan and Parrondo, 2010, 2012), but the generalization to mesoscopic and macroscopic processes is still an open question.*

For the atmosphere, we are indeed in a situation for which dissipation and global constraints - like the equator-pole temperature gradient – are placing the system out of equilibrium, and according to the current status of the information theory for dynamical systems, induces a time asymmetry reflected in a positive information entropy production. The precise link to the heat production in the atmosphere and to the amplitude of the global constraints is still to be addressed. This is also the case for specific processes like the wave breaking (Michel and Rivière, 2011) mentioned by the reviewer is also missing.

We have slightly modified the corresponding paragraph as:

"The novel approach of evaluating the (physical) entropy production based on coarse-grained time series at the microscopic level proposed by Gomez-Marin et al (2008) and Roldan and Parrondo, (2010, 2012) offers an important opportunity to estimate experimentally this quantity. Yet, when dealing with the dynamics of a macroscopic system like the atmosphere, the connection between the information entropy production, the physical entropy production, dissipation and global constraints, is still missing. The possibility offered by these advances however opens the way to improve our knowledge of the dynamics of the climate system, provided appropriate researches are done in that direction."

Thank you very much for drawing our attention on the work of Michel and Rivière (2011), now mentioned in the Introduction.

Minor comments:

Line 12: A quantitative assessment of the change of the entropy production (10% in the RCP2.6 and 30-40% in the RCP8.5) is missing in the result and conclusion.

Thanks for pointing this out. Now mentioned in the conclusions.

Line 110-114: As the main finding using the 15 model runs shows the diverged block entropy evolution depending on the realization, it would be useful for readers to briefly describe the difference in the realizations between 15 runs. (The difference is only in parameterization? or also in boundary conditions?)

As discussed in Pope et al (2022) and references therein, the only differences between the model versions are the set of parameter chosen. We add the following sentence in the description of the data:

"The model versions differ only by the choice of parameters and not by the forcing (Pope et al, 2022; Sexton et al, 2021)."

Line 124: "A clear trend … is visible, and chi^2 tests … are highly significant". Please provide the evidence (figure/table) of this sentence.

Thank you very much for pointing out this. I have now introduced the values of the Khi2 tests as:

"A clear evolution in the probabilities is visible. Khi2 tests of differences between the first and the last values have been computed. The Khi2 test of differences between the two distributions are 50, 176 and 214 for 3, 6 and 8 clusters, respectively. With the respective degrees of freedom of 2, 5 and 7, these values indicate that the two distributions are significantly different at a probability level much lower than 0.001. The Panel (d) shows the evolution of the Shannon entropy for the three partitions. Here however, the (static) information content does not change much as a function of time whatever the partition chosen."

Figures: labels (e.g. (a), (b),…) are too small to see. Please consider put larger labels in the upper left of the figure.

Thanks for pointing this out. The font size has been increased.

Figures 4-5: Legend would be useful.

We keep the panels without legends in order to have less crowded panels. The different lines are explained in the caption.

References:

Gaspard, P., 2004: Time-reversed Dynamical Entropy and Irreversibility. J. Stat. Phys., 117, 599-615.

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Pope, J.O., Brown, K., Fung, F. et al., 2022: Investigation of future climate change over the British Isles using weather patterns. Clim Dyn 58, 2405–2419

Roldàn, E. and J.M.R. Parrondo, 2010: Estimating Dissipation from Single Stationary Trajectories. Phys. Rev. Lett., 105, 150607.

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Sexton, D.M.H., McSweeney, C.F., Rostron, J.W. et al., 2021: A perturbed parameter ensemble of HadGEM3-GC3.05 coupled model projections: part 1: selecting the parameter combinations. Clim. Dyn., 56, 3395–3436.