

Review of **The remarkable inefficiency of stratocumulus** by Benjamin Hernandez, Martin Singh, Takanobu Yamaguchi, Graham Feingol, and Franziska Glassmeier

The authors present a detailed analysis of entropy production in shallow convection, focusing on two numerical simulations of open- and closed-cell convection. Estimating the entropy production in numerical models is a difficult undertaking, and the authors should be commended for their work. The primary finding -that stratocumulus convection is a rather inefficient heat engine as entropy production is dominated by moist processes- is well supported by the manuscript. They also show that shallow convection is particularly inefficient, as the share of entropy production by moist processes is much larger for shallow convection than for RCE simulations (with the exception of self-organized convection, which leads to an extremely dry climate). These are important results that deserve publication. The authors, however, fail to cite several previous studies that directly examine the role of moist processes in the efficiency of atmospheric flows, yielding results very similar to those presented in the present manuscript. I would support publication of the manuscript, but only after a major revision to improve the discussion of the existing literature.

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Main comments:

1. Discussion of the existing literature

The authors argue that atmospheric flow efficiency can be strongly affected by moist processes. While they do cite only a few studies that have tackled this problem, they fail to mention several important results on the topic. There are three key points that have been made before: a) water vapor and relative humidity have a direct impact on the mechanical efficiency of atmospheric flows, b) shallow convection is more affected by moist processes than deep convection, and c) several studies have investigated the mechanical efficiency of atmospheric flow outside of those mentioned by the authors.

a. Water vapor and mechanical efficiency:

Pauluis (2011) introduces the steam cycle as an analog of the Carnot cycle, in which the energy source is replaced by the injection of water vapor and provides an explicit expression of its mechanical output (see eq. 15 and 25 as well as Figure 3). A central finding in Pauluis (2010) is that the efficiency of atmospheric circulation depends on the relative humidity at which it operates. In particular, shallow convection in a dry environment would be particularly inefficient (see the discussion of Figure 3...).

In Sections 6, 7, and 8 of the manuscripts, the authors present some arguments for why the stratocumulus is inefficient. These arguments, in many ways, repeat parts of the discussion in Pauluis (2010).

b. *Moist processes have a much greater impact on shallow convection than deep convection.*

In Sections 6 and 7, the authors argue that the efficiency of shallow convection is quite small, with a much larger share of the entropy production attributable to moist processes. This is very similar to some of the results presented in Pauluis (2016). This paper introduces a methodology to reconstruct the thermodynamic cycles that underpin an atmospheric flow. It also argues that shallow thermodynamic cycles will be more strongly affected by moist processes (see the discussion after eq. 21):

“This implies that the relative importance of the Gibbs penalty is inversely proportional to the depth of the cycle, measured here by the temperature difference between the heat source and the heat sink.” (p.4417)

“For shallow convection, the scaling implies that the Gibbs penalty should be on the same order of magnitude as the maximum work.” (p.4418)

c. *Mechanical efficiency of atmospheric flows.*

The fact that moist processes significantly affect the mechanical output of atmospheric flows has been established in numerous studies. Many of these have been ignored by the authors, who mention only a limited number. In addition to the two papers mentioned above, I would point to:

- Several papers have investigated tropical cyclones (Pauluis and Zhang (JAS, 2017), Fang, Pauluis and Zhang (JAS 2017), Regibeau-Rocket, Pauluis and O’Neill (J Climate, 2023).
- Laliberte et al. (Science, 2015) show the impacts of moist processes on the global circulation.

2. Water lifting vs. precipitation-induced dissipation

Dissipation of kinetic energy by falling precipitation is a direct result of the fact that the atmosphere continuously lifts water. In RCE, the work done to lift the water balance exactly balances the precipitation-induced dissipation. This is not the case in the simulations presented here, as a large-scale subsidence continuously “removes” water from the domain. In this context, the work done to lift water exceeds the dissipation by precipitation. This is something that authors should document. In particular, they show that the open-cell convection exhibits a fair amount of dissipation by precipitation in contrast to the closed-cell case. However, it is likely that the work done to lift the water against the large-scale subsidence is quite significant (meaning larger than the precipitation-induced dissipation). While the argument could be made that the lifting does not directly correspond to an entropy source (albeit the water will fall at some point and thus dissipation will occur somewhere else in the atmosphere), it would be useful to document it and discuss it in the context of the efficiency (it is likely that it is larger than the generation of kinetic energy...).

Minor comments

L. 114 ‘the frictional effect on falling hydrometeors’: please attribute to Pauuis, Balaji and Held (JAS,2000) for the first discussion of rain as a dissipative process and a significant source of entropy.

Figure 1. It would be useful to document the water content as well, and possibly where the cloud layer is located in the vertical cross-section. (panels a and d).