

Review #2 of 'Indices of the Hadley circulation strength and associated circulation trends' by Pikovnik et al.

We thank the Reviewers for their suggestions. Answers to their comments are indicated in blue font.

Reviewer 2

The authors have made considerable effort to respond to or address the criticisms and suggestions of the reviewers. I am satisfied with the paper in its current form.

The word "however" on line 337 should be flanked by commas.

We have double-checked all "however" and added commas where relevant (incl. the reviewer's suggestion).

Reviewer 3

The authors should compare their findings on the energy-based metric with the mass transport metric found in Lucas et al (Variability and changes to the mean meridional circulation in isentropic coordinates. *Clim Dyn* 58, 257–276, 2022) who also found strengthening of the SH HC inferred from ERAI.

Thank you for pointing out this new study. While we acknowledge other than pressure system analysis of the mean meridional circulation including the study suggested by the Reviewer, comparing our results from the pressure system with other coordinate systems is beyond the scope of the present study. However, we list such a comparison as one possible way to expand on the present work.

In Conclusions (l. 321-324), we explicitly mention that the zonal-mean stream function can be computed as well in other coordinate systems:

"Note that evaluations of the HC strength and its trends may also profit from analyses in alternative coordinate systems, such as thermodynamic coordinates (Kjellson et al, 2014), moist isentropic coordinates (e.g. Wu et al., 2019) or dry isentropic coordinates (e.g. Lucas et al., 2021) that yield a different perspective on the mean meridional circulation."

We also mention in the Introduction (l. 47) that our focus is on pressure-coordinate metrics which are used most widely:

"We assess the sensitivity of the trends derived from the stream-function (1) based metrics in isobaric coordinates (Eq. 1) to the choice of the pressure level."

Note that we have not found significant strengthening of SH HC in ERA-Interim using any of our metrics besides water vapour transport metric (8), as indicated in Fig. 4d. While the energy-based metric shows the strengthening of the overall global zonal-mean unbalanced circulation, it cannot distinguish between the SH HC and NH HC. The apparent strengthening of the SHC in ERA-Interim might be due to the ambiguity of former Fig. 4. Thus, we have now separated the metrics describing NHC strength, SHC strength, and the total Hadley circulation strength in new Fig. 4 to avoid possible misinterpretation.

I find the figures 2 through to 5 and Table 1 hard to follow, along with the text. It would make it simpler if once each metric is defined, to refer them to their number.

We agree with the reviewer that the text should be simplified. We have thus provided more links/references to the Figures/metric numbers in the text and captions – see e.g. lines 202, 208, 217 in the track-changes file, Fig. 3 caption, etc. We have also unified the expressions for certain metrics: metric (7) is now referred to as the “average stream-function metric”, whereas we refer to metric (9) simply as “unbalanced energy metric”. A larger portion of Fig. 4 caption is removed, and the reader is referred to the Methodology section (2.2) and Fig. 3.

The authors concluded that metric 7 was the best choice due to their integration in both the meridional and vertical as opposed to single point or vertical integration only. While this is a valid point, the reader is left wondering about metric 8 and 9, which are the most interesting to compare with the wind-based metrics. A discussion is needed here.

We do not claim that the metric 7 is the best metric, rather that it alleviates problems of making strong conclusions based on a single point or level.

We have added a discussion. See l. 317-321:

“However, our results demonstrate that caution is needed when comparing HC trends from different studies using different metrics of the HC strength. In light of all the results, we would suggest using the average stream function as the metric of the overall HC strength whenever interested in the variability and trends in each Hadley cell separately. On the other hand, the unbalanced energy metric is a physically-sound choice for analysing the changes in the global zonal-mean circulation.”

Other non-stream-function metrics, such as (5), (6) and (8) only give a partial description of the HC features (e.g. upper branch in proximity of the ascending branch, only ascending branch or only lower branch, respectively) - see discussion in lines 132-137.