

Reply on RC1

Matic Pikovnik et al.

Author comment on "Metrics of the Hadley circulation strength and associated circulation trends" by Matic Pikovnik et al., Weather Clim. Dynam. Discuss.,
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We thank the reviewer for their constructive comments.

As the Reviewer points out, our suggestion that the measures of the HC strength that take into account both the meridional and vertical extent of the global HC are overall better indices than the HC measures based on local values may be intuitive. The time series of the stream function-based indices are aligned (Fig. 3) and highly correlated (Fig. 5), however, the differences become important when one computes the HC trends and quantifies their uncertainties. This is the first lesson from our comparison of independent measures of the HC strength. We applied the measures from previous studies to bring our results into the context of the reported trends in the HC strength. We agree that the trends based on other independent measures could be explored, such as the water vapor flow in Sohn and Park (JGR, 2013). This measure will be included additionally in the revised manuscript.

It is unclear how to quantify their relative relevance if we do not have a reference (or generally agreed) HC measure to which various other measures can be compared. It is in this context that we introduced a new, energy-based integral measure of the HC strength. The unbalanced energy of the zonal mean circulation is straightforward to derive for gridded datasets and it includes all 3 spatial dimensions of the unbalanced circulation. We are not sure what the reviewer finds confusing about the unbalanced energy measure, but we provide a further explanation here. Clearly, it is different from the stream function, but also omega and geopotential measure, and more research can be done to refine it, especially to differentiate between the northern and southern branches of the Hadley cell. But our figure A2 suggests that the global unbalanced energy is an adequate description of the HC. We believe that it is a suitable measure also for an intercomparison of reanalyses and climate model datasets analyzed in terms of the normal-mode functions.

In their specific comment, the Reviewer points out that ERA5 is a more advanced and therefore more reliable reanalysis dataset than ERA-Interim. We could not agree more and we will point this out in the revised paper. Although relatively few evaluations of the CFSR have been conducted and thus its performance is not well-known, we believe that CFSR is much more advanced than the NCEP-NCAR reanalyses. Yet, many researchers would argue that even the NCEP-NCAR reanalyses suffice for the description of the large-scale circulation. Even though ERA5 is available, many scientists rely on ERA-Interim and precisely a comparison of tropical aspects in the ERA5 and ERA-Interim, which have been the subject of several recent papers, motivated our study initially. The tropics remain the

regions with the largest analysis uncertainties (e.g. Žagar et al., 2020, J. Clim) but the four modern reanalyses (ERA5, ERA-Interim, JRA55, and MERRA) agree relatively well regarding the large-scale tropical circulation. The total energy of the zonal mean unbalanced flow shows positive trends in both ERA5 and ERA-Interim, although weaker in the former, a result consistent with the overall quality of the representation of large-scale circulation in the reanalyses. Note, however, that the only aim of choosing another reanalysis besides ERA5 was to show that the strong sensitivity of HC strength trends are not an isolated feature of a particular (e.g. ERA5) reanalysis, as stated in lines 262-265.

Response to technical corrections:

> L46: suggest replace '...are the trend... the pressure level.' by '...the trend... the pressure level are.'

Will be corrected.

> Section 2.2: this should go in the result section, not in the methods section

We agree with the proposed reordering.

> L177: suggest remove 'also'

Will be corrected.

> L182: what do the authors mean by 'merely showcase'?

Will be corrected to a more neutral form: Figs. 2, A3 showcase the stronger year-to-year variability of monthly means...