

Review of manuscript “wcd-2022-28”

Title: Decadal variability in extratropical Rossby wave packet amplitude, phase, and phase speed

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Summary and recommendation

This study investigates the decadal variability (and trends) of midlatitude Rossby wave packet (RWP) characteristics. These RWP characteristics, being their amplitude, phase, and phase speed, are investigated for different regions and seasons using various modern-era and historic reanalysis datasets. A more detailed analysis using ERA5 assesses how the spectrum of RWP amplitude and phase speed changes during the last four decades as well as how the more extreme RWP types with large amplitude and a quasi-stationary behavior change in two subperiods of 20 years.

Overall, I found the study very interesting, thoughtful and of high quality, well-structured and well written. In my view it forms a relevant contribution to the scientific understanding in this field. That saying, I also believe the study can be improved on a few aspects. These are detailed in three general comments and several specific comments, which may be considered by the author during the revisions.

General comments

1. Motivation of the study, and the interpretation and implications of the results

The manuscript describes very clearly the applied methodology and findings of the study. However, at times I was wondering about the precise motivation as well as the main message and implications of the study. In my view, these two aspects are rather poorly addressed in the current manuscript.

For example, in the abstract, the first line briefly refers to the potential influence of global warming on decadal variability of the upper-tropospheric circulation, but this aspect is further rarely addressed in the manuscript apart from a few lines in the introduction and the last paragraph of the summary and concluding remarks. I wonder whether this study has importance for – or is related to – a range of atmospheric phenomena, including extreme weather events, climatologically wet and dry conditions, climate variability patterns of the atmosphere or coupled ocean-atmospheric system. If so, it may strengthen the manuscript to mention these aspects. Moreover, the general message of the paper and its implication(s) remain unclear to me after reading the abstract. What is the main message of this study the reader should take home?

The second point – the main message and implications - also applies to most of the results (section 3.2-3.4). The analysis is worked out well and presented clearly, however, the interpretation of the results, the context of the findings in view of the existing literature, and the implications of the new findings are missing in my view. Do the findings have, for example, any relevance to better understanding weather extremes (the large amplitude quasi-stationary waves), trends in relatively wet or dry conditions (changes/variability in troughs and ridges), interannual and decadal climate variability patterns of the climate systems, or the response of the atmospheric circulation to global warming? The two following general comments also address this aspect for sections 3.3 and 3.4, respectively.

Analysis and presentation of the results in section 3.3

Although the results based on Fig. 9 are potentially very interesting, the analysis section 3.3 could be further strengthened in my opinion. For example, isn't of high interest to look specifically at how slow-

moving waves over North America and the Eurasian continent behave in summer in light of heat waves? How does the (lack of) positive trends in this part of the RWP amplitude – phase speed spectrum relate to findings of previous studies as for example cited in the introduction?

In addition, I found the text of this subsection quite difficult to follow. In the specific comments below are a few suggestions that may help to improve the clarity of the text.

Analysis in section 3.4

Although the analysis focusing on the high-E low cp RWP properties is potentially very interesting and relevant, this section left me with a few open questions and the feeling that a key element is missing. Why is the division of the analysis in two 20-year periods relevant? What do we learn from this analysis? Can we still speak about trends when the analysis is limited to 20 years or is it rather decadal variability that dominates the signal? Would even stronger and more regional signals emerge if one investigates four 10-year periods?

The focus of the second part of this subsection on high E, low cp RWP extremes is very interesting. To my surprise, however, this analysis is limited to the winter (DJF) season even though this analysis is motivated by both cold *and* hot weather extremes (as written in lines 379-380). I was expecting a discussion of these results for summer season (JJA) which is of special interest in context of heatwaves as mentioned before. Why is this not shown and discussed, apart from the note that figures for other seasons are included in the Supplement? As for the results in DJF over North America for the period 1999-2019, can these be linked to changes in cold extremes? In addition, has the author looked at trends in the extreme wave characteristics (large amplitude quasi-stationary RWPs) for the full 40-year period? Due to an increased sample size as compared to the 20-year periods, one may expect an increase of statistically significant trends in the spatial domain.

Specific comments

Title: The title speaks only about “Decadal variability”. From the analysis throughout the manuscript, I understand that both the decadal variability *and* trends are the main foci of this paper. Therefore, I wonder whether the author has considered rephrasing the title as “Decadal variability and trends ...”.

Lines 1, 3, and 400. The text speaks about “decadal variability” (lines 1 and 400) and “trends” (line 3). Since both aspects are investigated jointly, would it be worth to write instead “decadal variability and trends”? See also the previous comment on the title.

Lines 4 and 200. “may creep behind” sounds a bit colloquial, please, consider rephrasing.

Line 6. Here it becomes suddenly clear that more than one reanalysis dataset is used, while the term “historical ones” remains a bit vague and unclear at this stage. Please, consider writing in lines 3-4 “... utilizing various reanalysis datasets ...” and in lines 6-7 “... where 20th century reanalyses systematically underestimate E as compared to modern-era reanalyses.” (i.e., using the same terms as in section 3.1.)

Lines 14 and 294 Is “zonally-extended patterns” really what the author means to say or perhaps “zonally-aligned” or “zonally-oriented patterns”?

Lines 19-20. “thus reflecting at interannual-to-decadal time scales.” I cannot follow this phrase and how it is connected to the first part of the sentence. Please, consider rephrasing. In addition, wasn't the motivation of this part of the study (2nd half of section 3.4) linked to weather extremes (lines 379-380)? If so, then this sentence may end with addressing this aspect.

Line 28. Consider removing the word “anyways” as it sounds as colloquial word language.

Line 29-30. The first part of the sentence “To that end, ... wave properties” reads a bit difficult, please, consider rephrasing.

Line 39. Please, consider replacing “so far emerges” by, for example, “has emerged so far”.

Line 39. “A selection ... presented”. Please, state explicitly that you speak about previous studies.

Lines 40 and 43. The phrase “meandering of the 500 hPa geopotential height field” remains a bit vague. Do these studies address the amplitude, frequency and/or stationarity of these fields? Please, consider rephrasing in a more specific way if possible.

Line 49. Does “annual” refer here to “year-round” as in Line 42?

Line 55. Please, consider rewriting “for shorter periods within”, for example, as “for shorter periods within this 40-year period”.

Lines 59-60. Here, and on many occasions in the manuscript the unnecessary phrase “in this regard” or “in these regards” appears. Please, consider removing this phrase when possible.

Line 60. The phrase “local – in both space and time” reads a bit awkward. Please, consider rephrasing, perhaps as “diagnostics of spatiotemporal RWP properties”. The same for the phrases “local in space and time” and “local in space” which appear on many occasions in the manuscript. I wonder whether these be rephrased, for example, as “local, transient” and simply “local”, respectively.

Line 68. Please, consider rephrasing “... and report on possible trends in these regards”, for example, by “derive possible trends of these characteristics.”

Section 2.1. What exactly is the motivation to pick two 20th century reanalyses from the ECMWF? Would it be worth, instead, to use 20CR version 3 from NOAA along with CERA-20C and to leave out the more outdated ERA-20C? In addition, is there any indication to what extent the results based on CERA-20C are sensitive to the use of 1 specific ensemble member; i.e., how would results look like for different members and/or the ensemble mean? It is understood that changing the analysis accordingly may be too much to ask, especially since the focus of most of the study is on using ERA5 for the last four decades. Still, this question may occur to the reader and could proactively be addressed in the text.

Line 83. Which adjacent isobaric levels are also employed to test the sensitivity? And what came out of that sensitivity test? Later, this becomes clear in the conclusions section. I suggest replacing line 423 to this place in the manuscript.

Line 135. Please, consider rephrasing “with a view to illustrating” by “to illustrate”.

Line 140. Please, consider replacing “toward” by “in”.

Section 2.4. Fig. 1e illustrates the RWB phase speed at a specific time instant and shows values that range rather drastically from very low values < 4 m/s to over 14 m/s within the same troughs and ridges. Is this pointing to a weakness in the methodology or something that could be expected? Would it be worth considering spatially averaged phase speeds for the individual troughs and ridges to obtain more coherent results?

Lines 167. Please, consider replacing “manifests” by “illustrates” or “demonstrates”.

Lines 171. Consider referring here explicitly to the measures introduced, and write, for example, "... of the above introduced RWB properties...".

Lines 181-182. Consider writing "... , and thus, the null hypothesis".

Line 188-189. Consider referring here to Fig. 2 instead of later in the text.

Line 193. Please, consider replacing "scope" by "purpose".

Line 195. What is meant by "instrumentation"? I suppose the "observational system" in general, perhaps this can be phrased as such.

Line 201. Please, the sentence "The two study regions in DJF" reads awkward, please, rephrase.

Line 204. Please, consider writing "in this season" instead of "in this respect".

Section 3.1. This section describes for the NE Pacific and N Atlantic the decadal variability and trends for DJF and JJA. Although briefly discussed in lines 206-207, a very prominent feature in Fig. 3 seems to be an increase in E throughout the 20th century reanalysis for both regions and seasons. Should this result be more advertised, or is there a good reason to be rather careful with such statements as these trends may be subject to artificial trends within the 20th century reanalysis due to the changes in the assimilated observations throughout the 20th century? In addition, what is the motivation to show Fig. 3 for these two specific regions only? How do the results look like for the other regions? Even if not shown, it may be briefly mentioned.

Lines 211 and 212. Please, consider replacing "ones" by "reanalyses".

Lines 212-213, "This suggests... .. storm-track regions". Please, state explicitly that this statement concerns the 20th century reanalyses.

Lines 214-217. Interesting, are these differences between the two 20th century reanalysis datasets the result of the different reanalysis products, or rather due to the uncertainty resulting from the lack of observations to constrain these reanalyses? This could be addressed using the CERA-20C ensemble, see also the earlier specific comment "section 2.1".

Line 237. The meaning of "lower in magnitude trends" is not clear to me. Does the author perhaps mean "trends of lower magnitudes"?

Line 238. The "narrowing of the distribution" seems rather a "shift in the distribution toward lower E values"; is that correct? If so, please, rephrase.

Line 239. Instead of "larger confidence intervals", would it be more accurate to say "a reduced confidence" or "larger spread in confidence" as the wider shading band indicates a reduced confidence?

Line 242. Consider to replace "using local in space diagnostics of its properties" by "using diagnostics of local RWP properties".

Lines 246-247. Please, consider writing "The Mann-Kendall test accesses at each grid point ...".

Lines 251-252. Please, remove “in this regard”.

Lines 254-263. This is one of the paragraphs that make me wonder about the meaning and implications the findings, please, see general comment #1.

Lines 273-276. This sentence is unclear to me. Does it mean to say that the trends are not assessed at grid points where for more than 25% of the evaluated time intervals in the respective seasons no RWP is present? Please, rephrase for clarity.

Section 3.2.2. Specifically for variability in troughs and ridges, I wonder whether this can be linked to, for example, observed wet and dry conditions or if the patterns and their changes are for example related to circumglobal teleconnection patterns (see e.g. Fig. 7c). This results section may be strengthened by linking findings to existing literature, please, see further general comment #1.

Lines 295-299. This paragraph leaves me a bit puzzled. Are the above discussed findings still valid since changes in RWP frequencies are not included? Should changes in RWP frequencies be included in the above analysis to obtain meaningful results?

Caption of Fig. 7. Although written in the manuscript, consider saying in the caption of this figure that negative and positive values correspond to troughs and ridges for the purpose of clarity.

Lines 310-311. I suggest placing this sentence in the previous paragraph as it still discusses the Northern Hemisphere, and to start a new paragraph with the sentence “In contrast ...”, addressing cp changes in the Southern Hemisphere.

Lines 311-313. Interesting, these results seem to show a coherent signal. Has this also been observed in previous studies? Do we understand why this change occurs? Please, see also general comment nr. 1.

Lines 323-324. I cannot follow the sentence “In contrast to is defined”. Please, rephrase.

Lines 336-337. I have a bit of difficulty following the rather detailed scenarios sketched here. Isn't it the general idea of the analysis to assess the changes in the RWP amplitude-phase speed spectrum, that is, how slow to fast moving waves with small to large amplitudes change? Please, consider rephrasing to improve clarity of the text.

Lines 341-342. There are several problems with the sentence “Although any E.” For clarity, please, consider starting the sentence with “In C Asia ...”, refer explicitly to Fig. 9f, and consider discussing the dipole of decreased waves with high cp of any E and increased waves with low cp of any E.

Lines 339-347. These paragraphs are a bit hard to follow. Why are changes in DJF and MAM explained from the perspective of changes in E and cp, respectively, and not, for example, from both their changes? Is this because Figs 6 and 8 indicate largest changes in these seasons and regions for these specific measures respectively? If so, it may help the reader to state this. In addition, when speaking about the two N Pacific regions” (line 339) and “NE Pacific and N America” (line 343), it may be helpful for the reader to refer here to Figs 6a and 8b, respectively, to which these statements refer if I have at least understood the text correctly.

Line 348. To guide the reader, the sentence may start with “In JJA ...”.

Lines 16, 358, and 419; What is exactly meant with “no covariance is observed ...”. Does the author perhaps mean to say that no “systematic changes” are observed in trends of the RWP amplitude and phase speed spectrum?

Lines 360-361. I cannot follow the meaning of the sentence “Related to that in the Supplement of FW20)”. Please, rephrase or consider deleting the sentence.

Line 388. I suppose the author means “not defined” or “undefined”?

Lines 405-406. Consider writing “... seasonal mean E value in DJF, but not in JJA...”

Lines 421-422. What is the implication of this finding?

Line 434. Probably, write “when” instead of “where”?