Responses to Anonymous Referee #1:

Comments from Referee:

The authors propose a new method for evaluating the climatological conditions for the propagation of stationary Rossby waves as a function of latitude and height. This is based on calculating a "probability of favorable propagation condition for Rossby waves" (PrRo). I found this paper interesting and it is quite well written. This work has the potential to be a useful contribution to the literature, but I think some shortcomings of the work first need to be addressed.

Author's Response:

We would like to thank the referee for the constructive review and supportive comments that helped us to improve the manuscript

Comments from Referee:

It is asserted many times in the text that the proposed diagnostic for assessing the propagation conditions for Rossby waves is superior to previously proposed diagnostics or that other diagnostics are unsatisfactory, but the justification given for this seems weak. It relies principally on qualitative characteristics of wave propagation deduced from studies using idealised models of linear waves, summarised in table 1. However, the assertions made in the text that other diagnostics give unsatisfactory results are often not readily apparent to me in the figures. Also, the usefulness of such a diagnostic would be to better understand wave momentum fluxes in the real atmosphere, and it is not clear to me at least how well the results of the idealised studies predict the behaviour of the real momentum fluxes. The best way to demonstrate the usefulness of the new diagnostic would be to include more information about the EP fluxes for different wavenumbers, and show how well these fluxes correspond to what is expected given the diagnostic. For example, EP flux vectors could be plotted on top of the data shown with filled contours in figures 4, 8, 9 and 14. (In addition, I think it would be helpful to show EP fluxes on the panels in fig. 11 rather than separately in fig.12, to more clearly show how well the EP flux differences between the weak and strong vortex regimes correspond to the difference in PrRo.) I also think the horizontal component of the EP flux needs to be considered. These diagnostics were presented by Li et al. (2007), work which this paper is attempting to extend, and making these changes would bring the paper up to a similar standard to that work.

Author's Response:

We start from the assumption that any diagnostic tool attempting to provide a climatology of stationary Rossby wave propagation conditions should be consistent with the criteria listed in Table 1. Though we have provided a limited number of references for the criteria given in Table 1 many other studies (including studies employing reanalysis datasets) such as the study of Li et al. (2007), Lin (1982), Haung and Gambo (1982) and Hu and Tung (2002) and references therein are in general agreement with our assumptions. Too high values of MRIS (time Mean

Refractive Index Squared) (more than 500) northward of 75N in the lower stratosphere are not consistent with criterion 3 in Table 1, because the strong jet is expected to block wave penetration from the troposphere to the stratosphere. The MRIS is also not able to capture the meridional wavenumber dependency on the wave propagation conditions (criterion 2 in Table 1). For example in the Southern Hemisphere, the difference between time mean of for wave (2, 1), (2, 2) and (2, 3) in the stratosphere (above 100 hPa) is small, suggesting no considerable influence from the meridional wavenumber on the vertical propagation of planetary waves from the troposphere to the stratosphere. We also think that the MRIS results in high values of probability between 20–40N in the lower and middle stratosphere. This might be an over-optimistic result, because it is due to small positive values at these locations that exist throughout the winter season. In this respect the climatology of probability of positive refraction index squared does not meet criterion 4 in Table 1. Moreover as both the title and main body of the paper suggest the main focus of the current study is the vertical propagation of the Rossby waves from the troposphere to the stratosphere. For this purpose the horizontal component of the EP fluxes are not shown in this paper. Nevertheless the Authors agree that for fully understanding the propagation of Rossby waves, one must take into account both horizontal and vertical propagation of Rossby waves. We focus on the vertical component of the EP flux in our study, but we appreciate the importance of the meridional component. The horizontal propagation of Rossby waves are also important but this topic is not the focus of the current study.

Two more references are the followings:

Lin, B.: The behavior of winter stationary planetary waves forced by topagraphy and diabatic heating, J. Atmos. Sci., 39, 1206– 1226, 1982.

Huang, R. and Gambo, K.: The response of a Hemispheric Multi- Level Model Atmosphere to Forcing by Topography and Stationary Heat Sources (I) Foring by Topography, J. Meteorol. Soc. Japan, 60, 78–92, 1982.

Comments from Referee:

- I cannot find the definition of refractive index given on p.32294 in either of the given references Andrews et al. (1987) or Matsuno (1970) (and Kalnay et al. (1996) does not appear to discuss the refractive index, contrary to what is stated), and it is not obvious how the given definition could be derived from the material in any of those sources. Please give a reference for this quantity, or indicate how it is derived from the quantity given in another reference. The definition used here also has a dependence on meridional wave number which is not present in the definitions used in the other references (and which seems crucial for the conclusions relating to the propagation of waves with different meridional wavenumbers). Some discussion of the different physical assumptions made to arrive at this quantity compared to, say, those used by Andrews et al. (1987) to arrive at their equation 5.3.7 is therefore important to include.

Author's Response:

We apologies for the confusion and have clarified and complemented the existing set of references. We added two main references that explain a form of the refractive index of Rossby waves that depends on the two-dimensional wavenumbers (zonal and meridional wavenumbers). One can find this equation in equation 8 of Sun et al. (2014) paper. By studying these references one should easily understand the physical assumptions that are used to arrive at the presented definition of the refractive index of Rossby waves. The Kalnay et al. (1996) is not in the text to refer to the definition of the refractive index. It is used to refer to the NCEP-NCAR dataset. We added the flowing text in the paper for more clarification. “The definition of the current version of the refractive index of Rossby waves that depends on the two-dimensional wavenumbers (zonal and meridional wavenumbers) can be found in (Sun et al., 2014; Sun and Li, 2012). “

Two more references are the followings:

Sun, C. and Li, J.: Space–Time Spectral Analysis of the Southern Hemisphere Daily 500-hPa Geopotential Height, Mon. Wea. Rev., 140, 3844–3856, 2012.

Sun, C., Li, J., Jin, F., and Xie, F.: Contrasting meridional structures of stratospheric and tropospheric planetary wave variability in the Northern Hemisphere, Tellus, 66, 25 303, 2014.

Comments from Referee:

The importance of setting mu_Ro to zero for nˆ2>600 is not demonstrated anywhere, and it would be useful to know how important this added complexity to the diagnostic is. Could analysis similar to what is shown in fig.14 be done for the case with mu_Ro set to 1 for nˆ2>600 and set in the same way as shown in fig.7 for nˆ2<600?

Author's Response:

The region where refractive index squared is larger than 600 is not favorable for wave propagation. At these regions the zonal mean zonal wind approaches zero. This condition often happens in the upper troposphere/lower stratosphere where westerlies become weak in the winter season near the Arctic. Therefore most of the differences between Fig. 4 and Fig. 8 for Rossby wave (1,1) at the above-mentioned regions can be associated with setting mu_Ro to zero for nˆ2>600. We added a clarifying statement about this in section 4 of the revised version of the paper.

Comments from Referee:

The paper compares the new diagnostic with using the time-mean refractive index squared (MRIS in the manuscript), which is shown to be a much noisier quantity. A better diagnostic than the MRIS may be to take a "trimmed mean" of the refractive index squared, where the top and bottom X% of the data at each (y,z) position are excluded before taking the time-mean, where X could be 10, say. This would help to reduce noise by excluding very large positive or negative values. It would be useful to know whether this method performs much better than using the MRIS, and how much of an improvement the new diagnostic makes on this method.

Author's Response:

Thank you for the proposed method. Theoretically there are various ways in which one may reduce the level of noise in the time mean of the refractive index. The advantage of our proposed method is that it maps well and in a physical way on the list of criteria formulated in Table 1. Alternatively one can use other statistical methods like truncated means or trimmed means to reduce the noisiness. We will mention this in the outlook section of the paper.

Comments from Referee:

- I think it should be made clearer that the PrRo diagnostic is likely to be most useful as a qualitative indicator of wave propagation, rather than as a quantitatively accurate tool, given the limitations of linear wave theory on which it is based.

Author's Response:

We agree that both the refractive index squared and probability of the favorable wave propagation are qualitative tools. As Smith (1983) mentions, since the refractive index is a qualitative tool, one should not overemphasize the details of the refractive index. We do think that the probability of the favorable wave propagation provides an extended qualitative tool to study the vertical propagation of Rossby waves from the troposphere to the stratosphere. We added a clarifying statement about this in the conclusion of the paper.

Comments from Referee:

Minor comments: p.32293 L20-22 - the comment about focusing on vertical propagation seems unclear. If "there are also many studies using refractive index studying the horizontal propagation of the planetary waves", then it would seem important to look at the horizontal propagation. As I said above, I think the horizontal fluxes should be considered in the analysis.

Author's Response:

The major focus of the current study is the vertical propagation of the Rossby waves (as title and main body of the paper suggests). Though the horizontal propagation of the Rossby waves are an important issue they are out of scope of the current study.

Referee's comment:

p.32294 L6-7 - missing brackets around citation.

The Authors response:

It is now changed accordingly.

Referee's comment:

p.32295 L10 - "probabilities", not "PDFs"

The Authors response:

It is now changed accordingly.

Referee's comment:

p.32295 L22 - The flux has a minimum rather than a "discontinuity"

The Authors response:

the word minimum is now replaced by discontinuity in the text.

Referee's comment:

p.32295 L25 - the divisor in the mathematical expressions should be "10m/s" rather than "10".

The Authors response:

The units in this study are in SI and therefore the unit of the mean zonal flow is in m/s. The units are given in the equation as well.

Referee's comment:

p.32295 L26 - either "troposphere" should be "tropopause", or "at the" should be "in the".

The Authors response:

It is now changed accordingly.

Referee's comment:

p.32295 L26 - p.32296 L2 - this sentence could be made clearer e.g. "at these" -> "in the same"; "taking away the u-bar" -> "dividing by 10m/s rather than by u-bar"; "maxima is" -> "maxima are".

The Authors response:

It is now changed accordingly.

Referee's comment:

p.32296 L12 - what does "upper and lower limit" refer to?

The Authors response:

The upper and lower limits are referring to the maximum and minimum values of any variable that fuzzy logics tries to set various MVF for them. We added a clarifying statement about this in the paper.

Referee's comment:

p.32296 L15-16 - using the same nˆ2 notation to refer to both nˆ2 at different times and the time-averaged nˆ2 is confusing. Perhaps say "nˆ2(y,z) at different sampling times" rather than "nˆ2(y,z,t)"?

The Authors response:

It is explained in the appendix that the variable t is the time step and in the current study the daily mean values of the temperature and zonal wind are used in the calculations.

Referee's comment:

p.32296 L20 and p.32300 L15 - acronyms need to be defined (normally this is done separately in the text and in the abstract. In any case, it would be helpful for the reader for them to be defined again here).

The Authors response:

It is now changed accordingly.

Referee's comment:

p.32297 L11 - I think the u-bar<0.5m/s definition doesn't need to be given here, as it is given below, where it is more relevant.

The Authors response:

The Authors think that it would be helpful for the reader to precisely define the critical line at this point.

Referee's comment:

p.32298 L17 - "greater" should be "great"

The Authors response:

It is now changed accordingly.

Referee's comment:

p.32299 L16-19 - it would be useful to clarify here to refer to figs. 8 and 9 again.

The Authors response:

It is now changed accordingly.

Referee's comment:

p.32299 L26 - is this really "the most important information" or just a significant piece of information?

The Authors response:

It is now changed accordingly.

Referee's comment:

p.32300 L15-16 - some people may expect "weak vortex events" to correspond to sudden stratospheric warmings (SSWs), which is not what you mean. Perhaps your events should be named something like "weak westerly vortex events"? (It would also be interesting to know how your diagnostic performs in SSWs.)

The Authors response:

The refractive index is based upon linear wave theory e.g. during SSWs the linear wave theory breaks down and waves start to break and the waves are absorbed. Therefore we think that any diagnostic tool based upon the linear wave theory has this limitation. We added the following statements about this in the paper:

The WVR events do not correspond to the Sudden Stratospheric Warmings (SSWs) in the current study. Since during SSWs the linear wave theory breaks down and waves start to break and the waves are absorbed, the refractive index and probability of the favorable wave propagation (both are based on the linear wave theory) have limitations for studying the wave propagation during SSWs.

Referee's comment:

p.32300 L18 - it would be helpful here to give an equation or reference for the critical Rossby wave velocity.

The Authors response:

The critical Rossby wave velocity can be found in different books such as Andrews et al (1987).

Referee's comment:

p.32302 L4-6 - I suggest "study the difference in stationary Rossby wave propagation between different meridional wavenumbers" in place of "study the climatological effect of meridional wavenumbers on stationary Rossby waves propagation".

The Authors response:

The Referee's suggestion is included in the text.

Referee's comment:

p.32303 L1 - English is unclear.

The Authors response:

mPDF is a modified version of the regular PDF.

Referee's comment:

p.32303 L2 - some explanation of the choice of constants used in equation A2 would be helpful.

The Authors response:

The equation is a linear equation and constants show the slope and the point at which the line (between refractive index 0-600) crosses the y-axis in Fig. 7.