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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Diagnosis of Local Gravity Wave Properties during a Sudden Stratospheric Warming" *by* Lena Schoon and Christoph Zülicke

Anonymous Referee #1

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The paper by Lena Schoon and Christoph Zuelicke introduces a new tool for analysing gravity waves (GWs) in regularly gridded data such as from high resolution numerical weather prediction or other similar models able to resolve GWs. The tool has the advantage of being robust and implying only weak constraints on the wavelengths to be analyzed. A stratospheric warming case is discussed as a first application of the tool. The paper is presenting novel work and presents an innovative approach to GWs and thus merits publication in ACP. However, there are some points which are non-conclusive and which I recommend to remove and some details which need to be specified for the analyzed ECMWF case. Also, in my mind, the text could become more lucent and figures should be modified. Therefore I recommend publication after

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Discussion paper

major revisions.

Major comments:

1. Filter and filter response
At page 7, line 10 you introduce that you use a bandpass filter. You state the filter limits in terms of wavelengths. However, most filters have a spectral response rather than a hard limit. For the further interpretation this response is important. In particular, the short horizontal wavelengths cut-off might remove part of the mountain waves and favor waves excited by spontaneous imbalance and the long vertical wavelength cut-off could remove part of the GW spectrum in the high wind case (22 January). The latter would mean that you underestimate GWs for this case. Therefore please include a figure showing the filter response in terms of wavenumber or wavelength. In general, please explain why you need this filter at all.

2. Discuss the advantages and disadvantages of the technique
All techniques to analyze waves need to make a trade off between spectral and spatial resolution. The Hilbert transform is an innovative and elegant concept for high spatial resolution. Since one of the major objects of the paper is to introduce the new technique you should have a paragraph highlighting the properties of the new method. If I understand this correctly, the advantages are:

- The tool is mathematically well defined
- It is applicable to data of any dimension 1D to 4D
- Beside some spectral filter it does not make a preselection of the wavelengths, i.e. it is superior to e.g.
  - Fourier transform, which works on a fixed grid and distributes spectral power from any other wavelengths to that grid

  - S3D, which needs to preset the analysis volume and thus either smears out waves with small wavelengths or becomes unreliable at large wavelengths

- With FFT behind, it is fast

The prize you have to pay:

- You can determine only one wave vector per location, i.e. you attribute all the wave energy to a single wave. This does not allow to separate, for instance, the superposition of an upward and a downward propagating wave close to a reflection layer. (maybe that could be the reason for some peaks of wave action below the tropopause)

- With FFT behind some filter issues should apply

3. Introduce the idea
You could make better use of the introductory paragraph of section 2 and motivate the main idea of introducing the Hilbert transform. Perhaps something like: In this section we develop and validate an algorithm to extract wave parameters from equidistant three-dimensional data. For local diagnosis of waves, e.g. inertia gravity waves, phase-independent estimates of wave amplitudes as well as estimates of the wave vector are essential. For this we employ the Hilbert transform. The Hilbert transform shifts any sinusoidal wave structure by a quarter phase, i.e. turning a sine into a cosine. By constructing a new complex number consisting of the original field as real part and its Hilbert transform as the imaginary part, the absolute value is always the amplitude (square-root sum of sine and cosine), independent of the phase, the wavelength of the oscillation and without any explicit fitting of a wave. In addition the phase and, from the phase gradient, the wavenumber are determined. A tool called "Unified Wave Diagnosis" (UWaDi) is developed, which ...

4. Graphics
Please use axis scaling which comprise all data. Quite frequently in your figures the curves run out of the selected value range. That is quite unnecessarily hampering the interpretation since often a small extension should suffice.

5. Selection of individual profiles
The selection of individual profiles is somewhat arbitrary. With oblique wave propagation and finite vertical group velocity there may be other mechanisms contributing to the vertical structure than you would expect from a single column model. That should be noted in the text. In addition, profiles just in the vicinity seem to be quite different though similar filter arguments would apply. I think it would be more meaningful to select a longitude range of similar filter conditions and show the average profile for that range. Most of your conclusions would still hold and these are the valid ones. For the discussion of these profiles use the actual values (and not as sometimes now average values). For the critical wind filtering discussion you may assume upward propagation and then you should have a horizontal propagation direction and see whether a critical layer is approached.

6. Remove inconclusive parts
You compare to radiosonde data and find that they are different. However, there are many reasons why this could be the case and a detailed discussion is beyond the scope of the paper. Similar, there is no reason why wave action should be Gaussian shaped in the altitude profile, so a comparison of peak altitudes is not physically plausible. Please remove these discussions.

Specific comments:

P1L1 Why "maintain"? What do you want to say?
Except from a few spectral decomposition methods, the analysis of GWs is based on local methods, and at first reveals local wave phenomena. The calculation of zonal means then is a decision for generating a climatological mean state, but not a question

of the technique. Or are you talking about wave properties? Not all data allow, unlike regular gridded model data, to determine all wave properties.

P1L13 1000km (at the equator zonal wave 40) is more commonly called synoptic scale

P1L23 Complicated sentence

P1L24 "forbidden" is always a matter of the phase speed of the waves. Perhaps: as well as zones where wind reversals inhibit the propagation of GWs.

P1L25 "Models and simulations" That are not two equal terms to be linked by "and"; you need the model to perform a simulation.

P2L14 At altitudes below the sponge. Above about 40km GWs are very strongly damped and not realistic at all

P2L15 Even though the tropical portion of parameterised convective GWs is still too small Not clear what you want to say: ECMWF has a parametrization for convection. This likely results in a misrepresentation of the resolved subtropical/tropical gravity waves. ECMWF does not use a specific parametrization for convective waves, only a non-orographic GW parametrization.

P2L34 Other methods are 3D S-transform (Wright et al., ACP, in press), localized sinusoidal fits (Lehmann et al., AMT, 2012, Preusse et al., ACP, 2014) and 3D wavelets. These are more closely related to your own method and should hence be quoted here. These would be the methods you could delineate your own tool against in a separate paragraph.

P4L1 discrete Fourier transform

P4L4 ... a user-defined ... since you pronounce like "you" and not like "us", i.e. the word as pronounced starts with a consonant

P4L21 As I understand it, d is not the vector of spatial coordinates x,y,z as in the lines before (e.g. a[x,y,z]). Instead it corresponds to the spatial index of e.g. a wavenumber k_x for the x direction, i.e. the sums above are the sums over the three spatial dimensions. Correct? Please use different notations for different things.

P4L24 The noise threshold is essential for understanding the results. How is that calculated? Globally? Locally? Please include the definition.

P4L25 Why is this necessary after you have applied a band-pass filter already above?

P5L4 A one- ...

What happens for two waves of similar size in the same volume?

P5L14 sufficiently monochromatic

P7 Please state precisely which data you are using. Though both Cy41r1 and Cy41r2 use T1279 the effective resolution is different and for Jan 2016 both versions were generated.

P7L4 restricted -> reduced

P7L6 222km / cos(lat) for zonal direction; makes a factor of 2 at 60N and introduces an anisotropy in the cutting frequency

P7L10 These limits are coarse. ECMWF resolves in both relevant model cycles mountain waves with wavelengths shorter than 200km, i.e. you have performed here a preselection in physics.

P7L23 ... but not interacting with the mean flow Is that true? A wave refracted horizontally would conserve its wave action, but change direction and thus transfer momentum to the mean flow.

P7L26 in a mid- and low-frequency approximation:

Say -> From

P7L30 Please use always intrinsic and ground-based, respectively.

P8L1 omit: "one has to accept that"

P8L3 for the following analysis primarily wave action is used.

P8L7 The period 21 January to 21 February 2016 exhibits interesting wind features and is chosen for further analysis.

P8L8 zonal mean?

A change in wave action is supposed to be caused by a variation in the intrinsic frequency hinting at a steepening of GWs You mean relative to energy? Steepening = longer vertical wavelengths

Your analysis in F3 is 2D (in the horizontal plane)? Please highlight this.

P9L1 but not well above the filter!

P9LL1 What is the use of average values. In particular of e.g. average intrinsic phase speeds.

P9L9 Here you do a cross-comparison with four differences: location, time, generic data and analysis method. This is very difficult to interpret. Better keep at least time and space the same.

Figure 4: Please show also plots for wave action from UWADI

P9L24 Where is there any evidence for orographic waves in the figure?

In the stratosphere you can use the rule of thumb: 3km vertical wavelength correspond to 10m/s intrinsic phase speed. With a vertical cut-off of 15km that would mean that at 50m/s background wind speed most slow waves (such as mountain waves) are still in, and at 75m/s background wind speed a considerable part is removed.

How is a vertical wavenumber zero compatible with a long-wavelength filter edge of 15km?

Show the filter response for the respective axes.

Fig 6 Please use the same vertical axis for panels a and b

P11L13 "This finding contributes to our understanding to the density decrease with height which is not considered for the kinematic wave energy." Perhaps instead: The vertical profile results mainly from two competing effects: at increasing altitude density decreases. As the kinematic wave energy does not include density, we expect exponential energy growth for conservative wave propagation and hence a strong increase in regions of weak dissipation. Above 40km the mesospheric sponge of the ECMWF model sets in and cause strong, arteficial dissipation, which results in the decrease of wave energy at larger altitudes. In addition, ...

P11L15 Wave action should decrease above source altitude and there is no reason to assume it to be Gaussian. Please remove the sentence

P13L5 afterwards -> above

P13L6 the slow westward

P13L9 This is mid frequency approximation. If you use further approximations, note in the text

P13LL7 You use a single profile at one fixed time for your argumentation, but wave propagation may be oblique, requires time and the tropopause may cause partial reflection (what happens in the latter case?). Are your conclusions valid the same way for the profile at 40W? It would make much more sense to me to integerate over a small region.

P13L21 GWs are forbidden -> GW propagation is strongly inhibited. Unless $N^2 < 0$ you always have some GWs which may exist

P13L28 A longitudinal profile at 20° An altitude profile at 20° west ... Where do I see the wavelike structure in the figure?

P13L32 wave guide A wave guide means keeping the wave between two reflection layers as you would have it e.g. at the tropopause or mesopause for short horizontal wavelength waves. Open-walve region?

P17L4 Split this up: The tool is applicable to ... Here we apply the tool on divergence fields and limit towards long wavelengths thus isolating GWs. The procedure leads to reliable results for synthetic test cases. As a first application we run it on operational analysis data of ECMWF for a stratospheric warming case.

In future, the lack ... For comparing the phases you do not even need to have the Hilbert transform 4D. The most serious limitation is that you need ECMWF data at sufficient dense sampling which you could get from forecast data. For a first step you could assume upward propagation of the wave energy.

P17LL14 You use a pump=source and valve picture. 1.) You should have an introducing sentence that this is a picture for a more complicated process. 2.) That's based on Ron Smith's ideas? Is there any peer-reviewed article to quote? 3.) While the valve summarizes the properties of a wind profile, source is already such a general expression. Is it necessary to introduce a new word? In particular since source could work already in such a hydraulic picture.

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