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Interactive Comment

Interactive comment on "Investigation of inertia-gravity waves in the upper troposphere/lower stratosphere overnorthern Germany observed with collocated VHF/UHF radars" *by* A. Serafimovich et al.

A. Serafimovich et al.

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Reply on the interactive comments of anonymous Referee # 1

The authors thank the reviewer for the valuable comments to improve the submitted paper and reply to each comment (repeated in *italics*) below:

"The paper shows a case study of inertia-gravity waves, processed using an interesting variety of methods, and should be publishable. However there is repeated

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work from Peters et al. (2003, hereafter P2003), and some results depend on the choice of data processing."

The main aim of the first paper of Peters et al. (2003, hereafter P2003) was to study and to describe the appearance of inertia gravity waves downstream of a jet in the upper troposphere where the wind streak was induced during the pole ward Rossby wave breaking event (second phase) north-eastwards of an anticyclone. P2003 was mainly supported by radiosondes with additional usage of the VHF radar measurements from Kuehlungsborn. The estimation of the wave parameter in P2003 based mainly on the application of the Doppler equation (Eq 3.1 therein or Eq.2 in the present paper) where the intrinsic period itself were derived from 17 radiosondes, launched every 3 hours.

In extension of P2003, the main objectives of this continuative study based on detailed analyses of the data of two continuous running VHF/UHF radars located in Northern Germany are directed:

1) to get more insight in the structure of gravity waves with shorter periods in the upper troposphere. Gravity waves with periods below 6 hours could not be resolved by 3 hourly radiosondes.

2) to detailed analyses of the data of both VHF/UHF radars at Kuehlungsborn and Lindenberg, separated by about 265 km in order to investigate temporal and spatial differences of the observed waves and to identify common wave events by a cross-spectral-analysis, and

3) last but not least, to develop and apply different methods and algorithms for the estimation of the main characteristics of inertia-gravity waves and compare their results. Hereby the influence of possible vertical wind shear effects in the background

wind introduced by Hines, JAS, 1989, is taking into account.

We changed the introduction to emphasize these above statements.

"Specific comments"

Section 3.1 describes wavelet processing of same or similar data as P2003. This is already covered in a few sentences of P2003, (p.30, 'First of all a wavelet analysis was used (not shown here) in order to find some of the dominant frequencies of the unfiltered data, these defining the window for band pass filtering'), and resulted in different band pass limits from the submitted paper. Most of the paper assumes two separate waves, with very different properties; however this is based on Fig 3 where the waves are not clearly separate The paper should at least explain the reason for bandpass limits different from P2003, despite similar wavelet processing of same data. How dependent is Fig 3 on the choice of wavelet?"

1) In general, the wavelet processing used in this paper has been improved in comparison to the first investigations and statements in P2003. For example, now the estimation of significance levels and of areas at the borders in which the wavelet spectra are influenced by limited data (see below in 3) are included. In the revised version, we improved Figure 3 based on the results of previous detailed wavelet analyses. In the upper panel the wavelet power spectra of the time series of zonal and meridional winds are shown, now averaged over the altitude ranges 5.45-5.75 km (for Kuhlungsborn) and from 5.25 - 5.75 km (for Lindenberg). The presentation has been reduced to periods from 2 to 25 h for the time from 16-20 December. Especially for the Kuhlungsborn data, with these reductions both waves are now more clearly separated than in Fig. 3 of the previous submitted manuscript, where the wavelet spectra were smoothed too strong due to the before applied averaging in height from 4.75 - 6.25

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km.

2) In P2003, the time filter band was 4-18 h. We divided here the band to 8-18 hr and 2-8 hr based on the main findings of the wavelet transform from radar measurements (Fig. 3), which has been described in detail by this paper in contrast to P2003. Waves with periods of about 6h or smaller could not be resolved before by radiosondes launched every 3 hours.

3) Of course, the wavelet spectra as well as their validity at the border in height and time depend from the choice of the mother wavelet. The Morlet wavelet, for example, gives a better resolution in the frequency and a poor resolution in the time (or height). The Paul wavelet gives a better height (or time) localization than frequency dependence. For details see also Torrence and Compo (1998). The particular feature of radar measurements is that they are more limited in height than in time. Comparing both wavelet types the spheres at the borders in height or time in which the wavelet spectra are influenced by limited data, the spheres for the Paul wavelet are smaller than for the Morlet wavelet. Therefore we used the Morlet wavelet in the time investigations to receive finer frequency dependence and the Paul wavelet in the height analysis to receive a better height dependence of the wave packages. We have added in the caption of Figure 3 the used wavelet types and in Sect. 3.1 an additional sentence on the comparison of influenced spheres for both wavelets.

"Section 3.3, Table 4. Arbitrary height shifts produce a drastic effect on wave parameters in Table 4. Even if a 500m shift is plausible, the results are not then quantitatively meaningful."

We agree with the reviewer that the procedure is sensible to the selected height shift. To avoid arbitrary height shifts a realistic estimation has been used based on measured mean vertical phase velocities with an amount of about 0.06-0.10 m/s. To

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emphasize this approach, the corresponding text passage has been changed.

The assumption of other height shifts from the estimated in Table 4 means that the gravity waves have other vertical phase velocities, consequently also other observed frequencies or vertical wave numbers, or both parameters are different. This leads to quite other gravity wave parameters, which will then be quantitative meaningful. Furthermore, to check the sensibility of the height shift on the final results, we have added in the discussion in case (C) a 10% change to the realistic height shift, leading to variations of about 10% in the horizontal wavelength, and of about 5% in the observed horizontal phase speed, respectively.

"Figures 6,7 should include FFT of unfiltered data for comparison".

In contrast to the rotary spectrum (Figures 6, 7), the results without band pass filtering are shown in Fig. http://www.iap-kborn.de/radar/Mitarbeiter/Serafimovich/acpd/roto_kbn.gif averaged for the same periods. The maximum peaks of the vertical wave number corresponding to vertical wavelengths of about 8 km are probably determined by the dominating Rossby wave with upward directed energy propagation. However, the energy of this wave is much larger than the energy of gravity waves; therefore the figure overemphasizes properties of this wave and suppresses the information on gravity wave induced variations which are the main topic of the investigations in this paper.

"Figure 10 would be clearer with horizontal phase lines added. Is the marked phase difference for one wave at different times, not phase difference between radar locations at one time?"

Horizontal phase lines are now added to the Figure 10. It's true; the phase difference for one wave at different times is identical to the phase difference between

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radar locations at one time.

"p 4350, line 4,"'without additional temperature information': or vertical wind from profilers".

The sentence is extended "We have to note, that the horizontal wave propagation is uncertain with 180° without additional temperature information or vertical wind from profilers."

Minor comments

Tables 2,3 and their captions contain duplicate text. Data from Table 3 could be included in brackets in Table 2 (also Tables 5 and 6 can be merged).

Following this good idea, we have now merged Tables 2, 3 in a new Table 2 as well as Tables 5 and 6 in a new Table 4, divided into a left and right part for both analyses, respectively.

"Fig 2a,b is a duplicate of Fig 7a,b in P2003."

We cited the Figure 2(a,b) "after Peters et al.,(2003)"

"Why is zonal wind plotted in Fig 4 and meridional wind in Fig 5, preventing comparison?

The wind perturbations shown in Figures 4 and 5 are characterized by a superposition of atmospheric waves with different frequencies in the selected frequency band. We decided here to present the figures with the clearest signatures. However

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the estimation of all wave parameters itself is based on both components evaluated by different methods, e.g., with hodographs, rotary spectra, and especially with Stokes parameter spectra. We added a general remark to the end of Sect. 3.1.

p 4343, 3 lines up: 'decays just before the zonal jet maximum occurs' or, the wind rotates.

The wind field is determined by a clear zonal jet with variations from ~15 up to ~60 m/s from 17-19 Dec 1999. With the onset of the jet, the direction of the winds rotates from northerlies to values between ~85 and $\sim 115°$ (from North) during the jet maximum and turned back with the decreasing jet. To give a more clear description of the wind field we have changed the text. A vector plot of the horizontal wind field as derived from the Kuehlungsborn VHF radar is shown in Figure http://www.iap-kborn.de/radar/Mitarbeiter/Serafimovich/acpd/wind_field.gif

p 4348, line 1-3: bandpassed data agrees with wavelet results by definition, since wavelet results are used to decide the bandpass limits.

If there is only one dominating wave, then the bandpass filtered data derived over an extended height-time-range should agree with wavelet spectra for shorter time range or selected heights by definition. This is not obvious in every case, since the wind perturbations are characterized by superpositions of atmospheric waves with different frequencies in the selected frequency band and their height/time dependence. To clarify this topic, we have changed this part in the revised version.

"p 4356, 6 lines up: 'observed horizontal horizontal phase speed', delete one 'horizontal'."

p4356, 6 lines up: 'observed horizontal horizontal phase speed', one 'horizontal'

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is deleted.

Interactive comment on Atmos. Chem. Phys. Discuss., 4, 4339, 2004.