Dear reviewer #1,

we thank you for the comments and suggestions to improve the manuscript. Below we give some reply of the raised points, and will carefully consider all of them in the revised manuscript.

In the paper the relevance of the work for the understanding of SSWs should be discussed (SSWs are not mentioned at all in the paper).

Yes, we will do this in the revised version. Please also look at our response to comment no. 9.

It should be qualitatively discussed how the model simulations agree with observations of gravity waves during SSWs.

This is a good point, but it is hard to realize because we kept nearly all the conditions constant during our experiments. We save the GW drag data from the reference simulation, and then increased the GW drag in the specific region, and finally put it back into the model. We chose this cumbersome way, because otherwise we would get feedback mechanism which would in turn change the GW drag distribution. It was our intention to directly see the impact of this hotspot being not influenced by nonlinear effects. So, on the basis of the GW drag we do not see any changes. What is still changing is the horizontal GW momentum flux, which can be partly analyzed. It is just changing because of changes in the propagation conditions (background changes). The GW sources are fixed in MUAM thus, no additional GWs are generated. Ern et al. [2016] presented satellite measurements showing the absolute GW momentum flux during several years, also including SSWs. In general, they found out that the absolute GW momentum flux is increased (i) when the polar jet is strong and (ii) before and around the central day of a SSW and (iii) it is reduced when the zonal wind is weak. We tried to compare this to our GW output data containing the zonal and meridional GW flux, which we used to calculate the zonal mean absolute horizontal GW flux averaged between 60-80°N. It is scaled by density and presented in Fig. 1 in a time-height plot to show the temporal development. In contour lines the zonal mean zonal wind also averaged between 60 and 80°N is shown. The results in Fig. 1 are based on the H3 simulation (observed Asian GW hotspot). During the first 10 to 20 days the zonal mean zonal wind is decelerating, and the absolute horizontal GW flux decreases up to 70 km, which would correspond to the results from Ern et al. [2016]. However, in our simulation this effect is not very pronounced.
We will discuss this in the revised version.

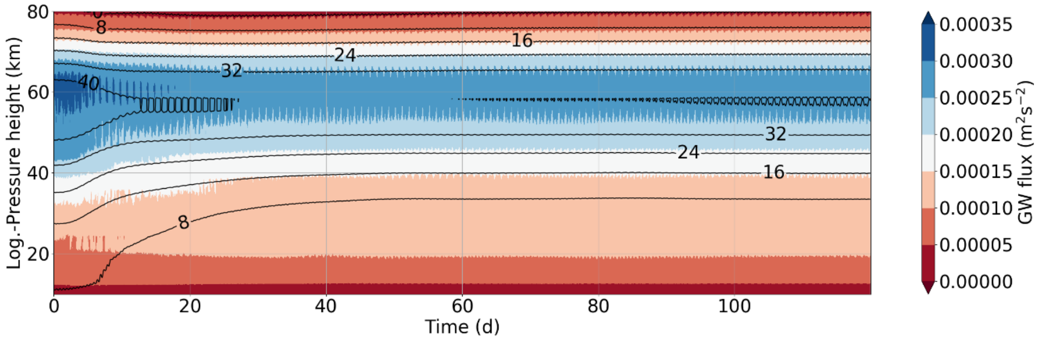

Figure 1: Zonal mean absolute horizontal GW flux scaled by density (color coding) and the zonal mean zonal wind (contour lines) in a time-height plot during the analysed 120 model days. The data is based on the H3 simulation (Asian GW hotspot).

1. pg.2, line 2
jet sources of gravity waves are not limited to frontal systems, and also the reference Plougonven et al. addresses jet sources of gravity waves more generally

We agree that 'frontal systems' is too specific in this case. It is one source generating GWs owing to adjustment processes. Thus, it can be left out and we will include jet sources.

2. pg.2, line 5

for the exponential increase with height constant background conditions have to be assumed and the gravity wave should propagate conservatively

We will include these conditions in the text.

3. pg.2, line 10

The expression "filtered out" could be misleading in this context. The waves moving into the direction of the wind, but faster, are not necessarily completely removed from the spectrum. Their amplitude growth, however, is hampered by their slow intrinsic phase speed.

This is an infelicity of the expression at this point. When they are faster than the background then the GWs are of course not filtered out but if they reach the critical line (background flow equal to the phase speed – for most of the GWs at the latest in the altitude of the mesospheric jet) the GWs are absorbed by the background flow or reflected back to the troposphere. We will correct it by adding that these GWs are partly filtered out when the phase speed of the GWs is equal to the background flow (mainly in the region of the mesospheric jet).

4. pg.2, line 10, suggestion:

"For this reason the wind reverses in the mesosphere due to GW breaking, while in the opposite direction to u travelling GWs deposit their momentum (Lindzen, 1981; Holton, 1982)."
"In mesosphere even GWs propagating in the opposite direction to u saturate and deposit their momentum. For this reason the wind reverses in the upper mesosphere/lower thermosphere (Lindzen, 1981; Holton, 1982)."

Thank you for this suggestion. Our sentence contains a huge amount of information and can be quite confusing wherefore your version is much better and we will include this one in our paper.

5. pg.2, line 20/21

Compared to the enumeration of mountain wave sources, the enumeration of convective regions generating gravity waves is quite short. Suggestion for keeping the balance:
"Typically, in the stratosphere satellite observations show a characteristic structure of enhanced GW activity in the subtropics that is caused by deep convection over Southeast Asia, America, Africa, or the Maritime Continent in the respective summer season (Jiang et al., 2004; Ern and Preusse, 2012; Wright and Gille, 2011)."

Thank you for this suggestions. This is a good idea to keep them in balance. Also because our observed Asian GW hotspot is partly convectively and orographically generated so that we should represent both trigger mechanisms (convection and orography) equally.

6. pg.2, line 22

Here you write "...objective determination of the GW drag from satellite measurements alone is not possible."
This is a too strong statement that also does not hold. Estimates based on satellite data exist, however contain large errors.
In the text following line 22 you give two references and state that GW drag would be derived from superpressure balloons and lidar data. However, these two references are used out-of-context!
The GW drag in these papers is based on model simulations alone. So far GW drag has not been derived from superpressure balloons because these balloons float on a fixed altitude, and vertical gradients cannot be inferred. To my knowledge, GW drag has not been tried from lidar data (please correct me if I am wrong), but I know that GW drag has been derived from radar data. Similar as GW drag derived from satellite, these estimates generally have large errors.

Therefore I would suggest the following rewording:
"Reliable estimates of GW drag from observations are generally difficult. There are attempts from satellite (for example, Ern et al., 2014; Ern et al., 2016), or from radar (for example, Reid and Vincent, 1987). Usually, however, uncertainties of these estimates are quite large. From model studies there are indications that GWs can break already in the lower stratosphere (LS), for example Plougonven et al. (2008), or Constantino et al. (2015)."

We agree with your point of view. Maybe our statement is a bit misleading because we meant the measurement of the GW drag itself. As you said, it is possible to derive the drag by making different assumptions which create large errors. We will change this part based on your suggested text.

7. pg.3, line 29
This comment is not relevant for the current paper, but may become relevant for future work. On pg.3 line 29 you write that GW potential energy of the MUAM model would be tuned "... based on potential energy data obtained from GPS radio occultation measurements" Tuning the model towards GW potential energies observed from GPS may introduce large biases. It has been shown by Rapp et al. (2018) that vertical filtering of GPS soundings for obtaining the gravity wave signal does not remove larger scale structures having short vertical wavelengths, such as inertial instabilities at low and mid latitudes, or Kelvin waves in the tropics (Ern et al., 2008).

Yes, that's true. This is something we kept in mind when we were analyzing the GPS RO data which as well do not consider Kelvin waves, for example. Before we included the globally weighted potential energy data as zonal mean into our model, we had an artificial zonal mean GW amplitude distribution based on a hyperbolic tangent function depending on the latitude which was less realistic then the one derived from the GPS RO data. We thought it is a good idea to replace it but of course we should not forget that these data does not include all small-scale disturbances. We will discuss this further in the revised version.

8. pg.15, line 30
Gravity wave hotspots do not only occur over mountain ridges. Local hotspots can also be caused by the GW jet source mechanism. For example, Ern et al., 2016 find enhancements of GW activity that are linked to jet exit regions. Possibly these hotspots are missed by AIRS because of its limitation to gravity waves of very long vertical wavelengths. The proposed follow-up study is therefore a promising way to proceed, but should not be limited to the positions of orographic GW hotspots. Also longitudinally varying positions of jet-related GW sources could be important.

Thank you for this suggestion. In this paper the position of the analyzed GW hotspots does not explicitly refer to a specific source. Regarding orography there are no obvious sources, when we are displacing the GW hotspot latitudinally. But of course, some of these GW hotspots can be purely hypothetical connected to jet exit regions.
For this purpose, we are planning to write another paper about the longitudinal displacement of the GW hotspot. When we are displacing the GW hotspot longitudinally then we do not only capture/represent orographically generated GWs. Because this displacement is partly along the polar front jet which may generate GWs we indirectly consider this kind of GWs. Then, we will also include this type of GW as possible contributor of the artificial GW forcing.

9. General comment for the discussion throughout the paper:
For midlatitude forcing some of the findings are very similar to the situation during SSWs.
- vortex slowdown and shift (Fig. 3)
- stratospheric warming (Fig. 4)
- changes in the activity of the SPW1
These similarities should be discussed in more detail and put into the context of SSWs. For example, it has been suggested recently by Albers and Birner (2014) that gravity wave forcing at

midlatitudes could be important for the onset of SSWs. Also satellite observations of gravity waves show stronger GW drag at mid or even low latitudes prior to major SSW central dates (Ern et al., 2016). In the same paper strong gravity wave activity and GW drag was seen in the polar vortex during 2011. In this year, however, the vortex was very stable and confined to high latitudes which also confined gravity wave activity to high latitudes, apparently without affecting the stability of the vortex. This supports one of the main findings of your study and should therefore be mentioned.

Thank you for this comment! Indeed, the results show specific characteristics which are comparable to SSWs. In this case, we did not create a SSW but caused a preconditioning of the polar vortex owing to the aspects (SPW activity, displacement and slight warming) you already mentioned. But this also strongly depends on the strength of the forcing (stronger forcing can also lead to a total breakdown of the polar vortex). Based on this fact we will include this topic (preconditioning of the polar vortex) in our discussion and will also refer to this topic in the introduction.

Other Comments

1. pg.2, lline 28/29: Please rewrite the following sentence for better legibility! "This study is focusing on different GW breaking areas in the lower stratosphere along and the effects on the middle atmosphere highly depending on the position."

We will rewrite this part such as: this study is focusing on different GW breaking areas in the lower stratosphere and their effect on the middle atmosphere dynamics.

2. pg.2, line 29: who were concentrating ! who were focusing

We will replace the word as suggested.

3. pg.3, line 2: shifting meridionally the EA/NP hotspot along its fixed longitude range! shifting meridionally the EA/NP hotspot keeping its longitude range fixed

We will change this sentence as suggested.

4. pg.3, line 23: interval, in which ! interval in which

We will correct this.

5. pg.4, line 3: refer to the mid ! referring to the mid

We will correct this.

6. pg.4, line 17: reproduce ! reproduces

We will correct this.

7. pg.5, line 2: observations but the ! observations, but the

We will correct this.

8. pg.5, line 3: jet filtering some of ! jet filtering of some of

We will modify this sentence.

9. pg.7, line 4: is shifted toward ! that is shifted toward

We will correct this.

10. pg.7, line 14: kmat ! km at

We will correct this.

11. pg.8, line 14: west wind ! westerly wind

We will correct this.

12. pg.11, line 10: more SPW 1 are excited, ! SPW 1 excitation is strengthened,

We will correct this.

13. pg.12, line 2: fluxes and its ! fluxes and their

We will correct this.

14. pg.13, line 3: atmopshere. ! atmosphere.

We will correct this.