Comparative study between ground-based observations and NAVGEM-HA reanalysis data in the MLT region G. Stober et al.The authors present a study of tidal variability at altitudes of 75 to 110 km in the north-ern mid-to-high latitudes, emphasizing periods around stratospheric sudden warmings. They compare observations from a number of sources, most notably meteor radars, to NAVGEM-HA analyses. They also present a diagnostic tool called an adaptive spectral filter. It is not clear to me what the central purpose of the study is: is this a validation of the NAVGEM-HA reanalysis? is this a methodology paper introducing the adaptive spectral filter? Is this a science paper focusing on the variability of the tides around sudden warmings? I am not sure what the reader is supposed to take away from this paper

One symptom of this is that the bullet-point list of conclusions in the final section is vague. Several bullet points claim that the reanalyses are ’realistic’ and suitable for use as lower boundary conditions, but criteria for this claim are never discussed, and other validation papers cited seem to have drawn these conclusions already. Variations in the tide are attributed to variations in the ’wind patterns’ of the middle atmosphere but no evidence is provided to support this claim. The merits of the ASF methodology (e.g. error estimates) are touted but never used. And another ’holographic reconstruction’ methodology is used in the discussion section without ever being introduced.

I find the figures difficult to read, numerous, and not clearly organized with respect to the discussion, again my sense is that this is a symptom of the paper not having a clear purpose. Finally, the text of the manuscript is still rough around the edges, with incomplete sentences and missing references.

I’ve included a list of specific comments below. On the basis of the above comments it is my opinion that this manuscript should be substantially revised before it can be considered suitable for publication.

General Reply:

We thank the reviewer for his constructive comments to the submitted paper. We have revised the manuscript according to his suggestions and included new and the missing citations, added paragraphs providing some of the suggested information and restructured parts of the manuscript to provide a more consistent narrative.

NAVGEM-HA has not yet been validated in the climatological sense using independent ground base sensors. It is not worth to investigate the short time variability, if the seasonal climatology is not well-reproduced. The short-term variability and cross-validation of NAVGEM-HA fields with respect to specific waves is a new way to benchmark meteorological analysis systems, but is also

tied to the methodology to extract the information, which is in the case the ASF technique. Although, we don’t intent to focus on the method itself, it is necessary to provide essential information on the technique.

Finally, we present a detailed discussing of the tidal variability related to a highly relevant coupling process at the middle atmosphere (SSW) and its relation to alter in this case the semidiurnal tide. We discuss potential affects in the context of lunar tides, which provides an excellent example and demonstrate the potential of combining various local and global data sets to analysis effects on time scales that are hardly accessible with other methods at MLT altitudes.

In so far, we want to keep the general content of the paper, but did, as suggested, revise the structure and moved some paragraphs to get a better structure. We hope that the revised version satisfies the reviewers suggestions and comments.

Detailed answers are provided below for each comment.

Later there will be a tracked changes file uploaded. The red color labels removals, the blue color insertions.

Specific Comments:

Section 2:

Data and Model output:

Comment:

The periods for which data are available for each data source are not given. Neither are the ’analyzed periods’ specified.

Reply: (Page: 3 line:3-4)

This information is provided in the section about mean winds.

Comment:

To what end have the temperature observations been included?

Reply:

There are only a few ground based temperature climatologies available. So far NAVGEM-HA was not yet compared to independent temperature observations. Satellite temperature measurements from MLS and SABER don’t provide an independent data set due to the assimilation.

Comment:

Are the NAVGEM-HA outputs analyses or reanalyses? To what extent should the reader expect the tidal structures analyzed in this paper to be directly constrained by assimilated observations?

Reply:

NAVGEM-HA is a meteorological analysis, we removed through the manuscript the term reanalysis.

Comment:

What kind of sponge layer does the forecast model employ and over what levels does it act?

Reply: (Page: 5 line: 18-28)

We provide this information in section about NAVGEM-HA.

Comment:

There are missing citations in the first and third paragraph of section 2.3.

Reply:

The missing reference is now added.

Section 3: Diagnostics

Comment:

The details of the ASF are vague to the point that it is difficult to assess the validity of any of the results. For instance: how is the sliding window determined? What windows are in fact used? What is the purpose of the scaling factor? How is the vertical ’regularization’ carried out? If these details are given in previous studies this should be clearly stated, if they are novel they should be justified. No specifics are given about how planetary-scale waves are accounted.

Reply: (Page: 31 appendix A1)

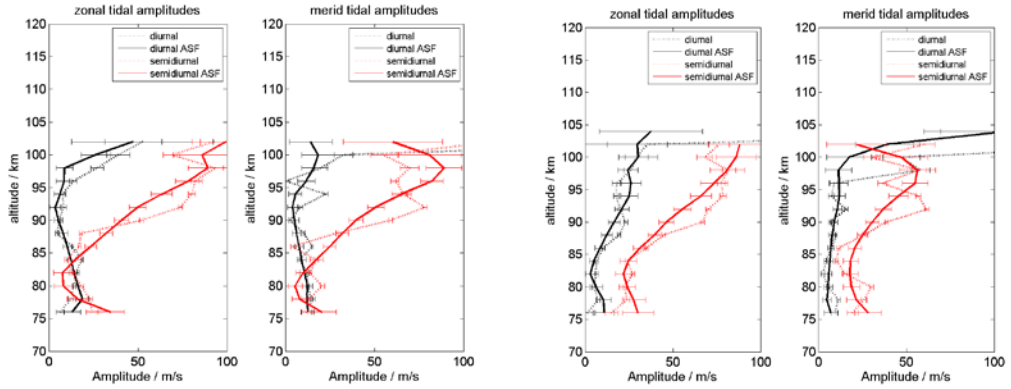
We added the reference of previous developments of the ASF technique and how it was validated. Here we just mention the most important information of what was used in the ASF analysis. Further, we added a sentence outlined in more detail how the scaling factor is used to determine the window length.

We also add some figures in the appendix outlining how the technique works and about the error statistics. However, it will be critical for the readability of the

submitted paper, if much more details about the ASF implementation are added to the paper.

The implementation of the ASF is in Fortran 77 and Matlab based on modified numerical recipes algorithms. Basically we generate for all times and altitudes Jacobian matrices, which can be written as one large block diagonal matrix (in development) or we keep each Jacobian (this is the current version) and create a cubic tensor (for each tidal frequency a separate layer due to the different window lengths). Then we solve each Jacobian and store the solutions into a vector. First for the diurnal tide. These solutions are used as regularization for the next layer with the Jacobian of the semidiurnal tide and so forth. Finally, we select all altitudes falling into the vertical averaging kernel and perform a weighted linear fit to all coefficients.

Below are two examples from the same day in 01st February 2010 observed at Juliusruh to visualize how the ASF reduce a potential contamination due to gravity waves with short vertical wavelengths. Filtering just in time domain would move energy from such gravity waves to the tidal energy budget. The plots also indicate that at the upper and lower edges the errors get very large, which is expected as we have no longer enough measurements to perform a statistical reliable regularization. The plots contain just the profiles obtained at a specific time at the day without temporal averaging in the case of the ASF. Therefore, the errorbars are scaled by 1/sqrt(n) to make them comparable to the temporal averaged values plotted as dashed line.



Comment:

Details of the ’holographic reconstruction’ methodology discussed in Fig. 12 should begiven in this section.

Reply: (Page: 25 line:2-16)

Holographic techniques are standard physical methods to derive radar parameters. However, we agree to the reviewer that it might be better to include a short paragraph describing how the hologram is obtained and used here in.

Section 4: Results

Comment:

Figure 1: What time periods have been used to create these figures? My reading of the figures is that the summertime reversal of the zonal winds from easterly to westerly occurs at higher altitudes in NAVGEM analyses than in the radar data, and that the southward meridional winds are not as strong. Is this the bias that is reiterated in the conclusions? Has this bias been noted in previous work?

Reply: (Page: 3 line:3-4)

We expanded the description of NAVGEM-HA, as the reviewer had already suggested this in the data and model section. This comparison is one of the first ones using summer-time NAVGEM-HA data for a comparison with independent ground based observations. The systematic differences in magnitude were not yet reported in a similar way in previous studies, although they were present there as well, but less obvious.

Comment:

Figure 2: The warm anomalies in NAVGEM-HA near 95 km are plausibly a sponge layer effect - one would need to know details of the sponge layer to assess this claim.

Reply: (Page: 5-6, lines 27-6(next page))

This point is also related to the model description section. We clearly remark to not use the summer-time data above 90 km due to sponge layer and extrapolation effects. The uppermost recommended usable pressure level in NAVGEM-HA after removing the sponge layer corresponds to a geometric altitude of 89/90 km at high and middle latitudes for the summer months. For the winter months the geometric altitude is between 91/92 km. Just focusing on the altitudes below 90 km, the agreement is much more reasonable compared to many other GCM’s.

Comment:

Figs. 3 to 5: The structure of the discussion (which discusses first observations then NAVGEM-HA) does not match the structure of the figures. More importantly the tidal amplitudes and phases in NAVGEM-HA do not look like close matches to observations to my mind. This would be a useful place to make use of the error propagation capabilities of the ASF methodology that are claimed as a benefit in later discussion.

Reply: (Page:5 line:18-28)

We moved some paragraphs sections to the model and data description sections to get better structure of the manuscript. Due to the required large size of the figures there is a clear mismatch between figure positions and text, however, this is very difficult to be fixed in the draft stage.

The mismatch of the tidal phases and amplitudes in NAVGEM-HA and the meteor radar at altitudes above 90 km is attributed to sponge layer and extrapolation effects during the gridding to geometric altitudes.

Comment:

Figs 4 to 6, 7 to 9: Again the structure of the figures and the discussion don't match up.

Reply:

Due to the restructuring of some paragraphs this should have been improved.

Section 5:

Comment:

The merits of error propagation through the ASF methodology has not been demonstrated, nor has the benefits of the vertical resolution. I can see that these are both desirable features but no demonstration has been made of their value or correctness.

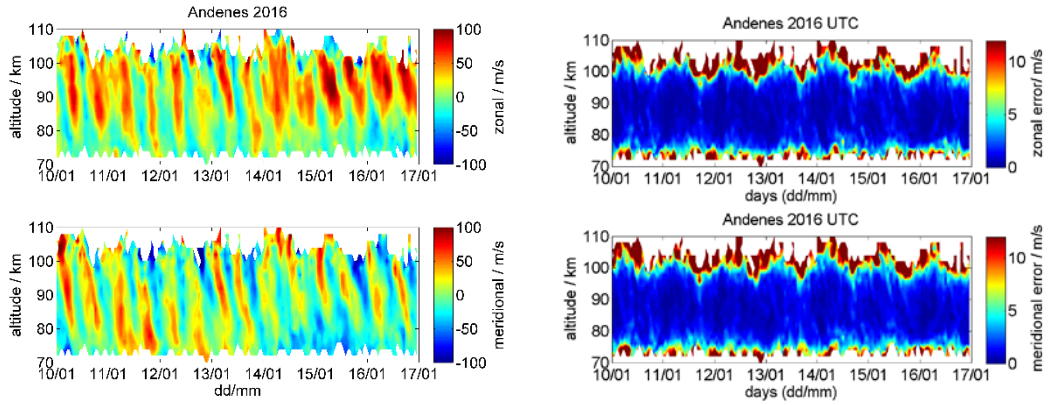
Reply:

The ASF methodology was already used in several publications before (Stober et al., 2017 (temporal ASF only), Stober et al., 2018a (gravity wave analysis using a MST radar), Stober et al., 2018b (retrieval of horizontally resolved meteor radar winds), Wilhelm et al. 2019 (mean tidal and wind climatologies as well as long term change analysis including significances based on full error propagation) and Baumgarten et al., 2019 (introduction and validation of 2D ASF using MERRA and lidar temperatures) as well as Pokhotelov et al. 2019 (cross comparison of GCM tides and meteor radar tidal climatologies). The benefit of wind retrieval errors and advanced statistical analysis including ASF filtering for spars data was demonstrated in Gudadze et al., 2019). So far substantial methodological problems were not raised by the other reviews and did not occur comparing the analysis to other climatologies.

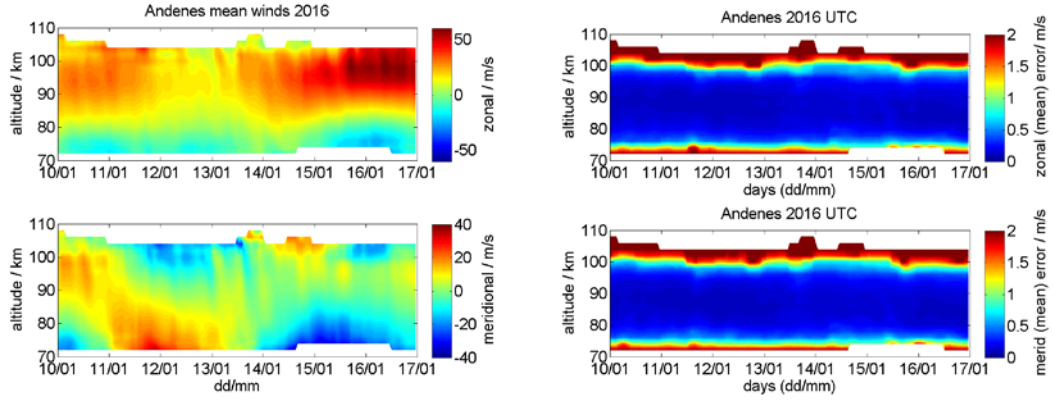
The benefit of the error propagation is difficult to demonstrate. We propagate the error from the statistical uncertainties derived from the radar doppler velocity, which is based on the raw voltage statistics at the antennas, until the finally obtained wind or tidal component. The results presented herein are based making use of all these developments and we are sure there are differences, if we would redo all the analysis without such a weighting by the statistical uncertainties and the involved non-linear error models. If the results could be obtained without all the involved mathematics – there would be no benefit.

Please have a look on the following sequence of pictures. The left panel shows always the original parameter as zonal and meridional component, the right panels show the corresponding measurement uncertainties (here denoted error) in m/s.

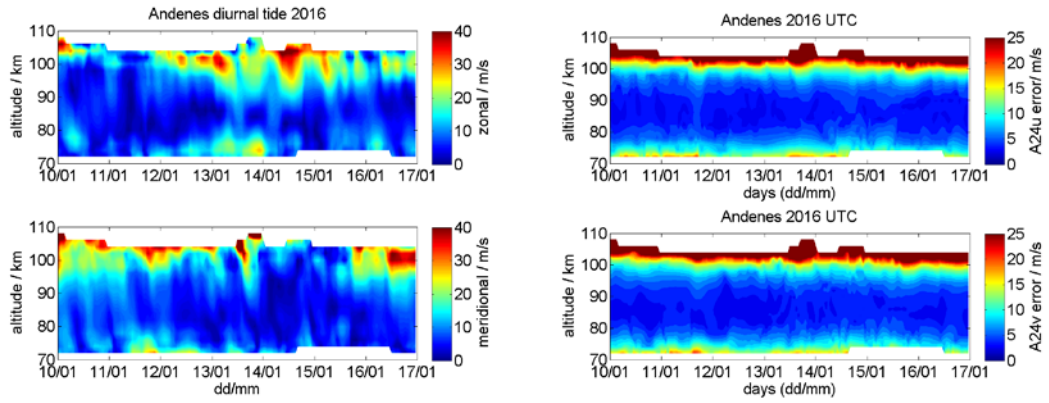
Hourly winds computed using the algorithm presented in Stober et al., 2018.



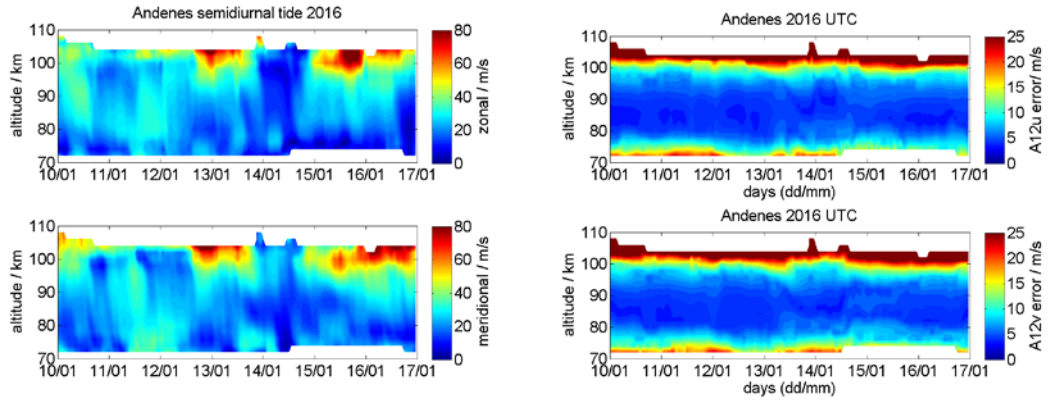
Daily mean winds after decomposing the time series with the ASF.



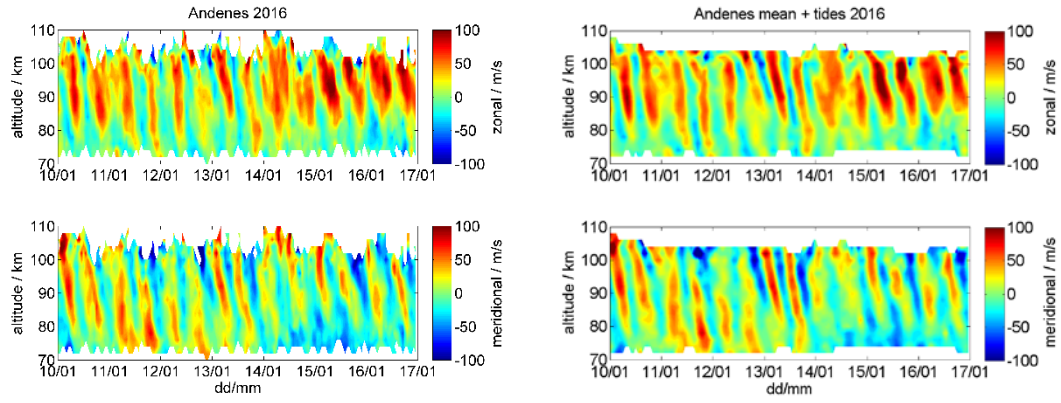
Diurnal tidal component



Semidiurnal component



Comparison of hourly winds and reconstructed time series from mean winds and tides



The reconstructed time series captures remarkably good the intermittent behavior of the observed tides and of the background mean winds.

Comment:

p22 lines 33-35: SSWs can perturb the middle atmosphere for months, as was the case in both the 2008-9 and 2012-3 events considered here.

Reply: (Page: 26 line:10-11)

The reviewer is correct. We rephrase this sentence to avoid confusion about the seasonal impact of SSW (Baldwin and Dunkerton, 2003 and many other publications). We now state that the wind reversal and cooling at the MLT last only for a few days during a SSW.

Comment:

Figure 12: What is the difference between the upper and lower panels? Also, the units for the period are wrong.

Reply:

We correct the unit and uploaded a new Figure including a vertical line indicating the onset of the SSW using the criteria presented in McCormack et al., 2017.