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Interactive comment on "Climatologies and long-term changes of mesospheric wind and wave measurements based on radar observations at high and mid-latitudes" *by* Sven Wilhelm et al.

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Interactive comment on "Climatologies and long-term changes of mesospheric wind and wave measurements based on radar observations at high and mid-latitudes" by Wilhelm et al.

Anonymous Referee #1

General reply: We thank the referee for the recognition of the work and for constructive suggestions and comments that help to improve the paper. This paper focuses on observations and it is intended to provide a summary and diagnostic of MR measure-

ments as reference for other observations and also GCM models. A detailed investigation of the possible causes for all the effects is beyond the scope of the paper and has to be done in additional works. The revised version can be found in the supplements.

Specific comments:

- The abstract could be slightly improved. Summarize the kind of difference you observe for the DT and SDT (page 1, line 8). At the end, maybe include in one sentence what the main influence of the 11-year solar cycle is.

Reply: Thank you for the comment.

We added to the abstract the following part: The diurnal tides show nearly no significant long-term changes, while changes for the semidiurnal tides differ regarding altitude. Andenes shows only during winter a tidal weakening above 90 km, while for CMOR occur an enhancement of the semidiurnal tides during the winter and a weakening during fall. [. . .] The influence of the 11-year solar cycle on the winds and tides is presented. The mean winds exhibit a significant amplitude response, for the zonal component below 82 km during summer and from November - December between 84 and 95 km at Andenes and CMOR. The SDT show a clear 11-year response at all locations, from October to November.

- Please check the use of the word "tendency" throughout the manuscript, if it is always scientifically appropriate. It may occur too often in some paragraphs (e.g. page 8).

Reply: Thanks for the comment. We checked and reformulated sometimes the word "tendency". In the manuscript we avoid to use the term "trend", which would be an often used alternative, simply because for a trend requires at least 30 years of data.

- Page 1, line 16: For completeness, also passive microwave radiometry from ground can provide wind measurements (at least up to the upper mesosphere).

Reply: We added the passive microwave radiometer to the list.

- Page 2, lines 5ff: Here I suggest to add a small paragraph on GCMs in regard to what is state of the art and in context to this study. Have you considered to explicitly compare your observations to GCM simulations?

Reply: Within the current study we don't want to compare our observations and the corresponding filter approach to GCM simulations, but we are planning to do a comparison between our findings and GCM simulations. Furthermore, we are planning to applicate the adaptive spectral filter approach on other instruments and GCM data.

We added a small part regarding GCM-state of the art: Basically, climatologies of winds and tides in the mesosphere are well represented in GCMs. With the onset of the mesopause, differences occur between models and observations, which are shown in several studies. Yuan et al. (2008) showed differences between 3 models and observations, as well as, also between models itself, by mentioning that the height of the summer mesopause differs. Stronger differences occur during the winter, opposite prevailing wind directions occur above the mesopause between models and observations Pokhotelov et al. (2018). A reason for these differences is probably based in using different gravity waves parameterizations.

- Page 3, lines 13-14ff: Can you give here a short explanation why the mentioned residuals are a good indicator of GW activity?

Reply: We did look at the total spectrum of fluctuations and identified the different wave types and put notch filters to wave with well-defined periods such as tides. The 8-hour tide is usually considered as most challenging to be extracted and contains also a significant amount of GW activity. This is also the reason why we do not provide a climatology for this tide in the manuscript.

We added to the manuscript: The gravity wave activity is the residuum, which includes all fluctuations different than tides and planetary waves.

- Page 4, line 24: Regarding the composite of different radar systems, is there a ho-

mogenization applied to the different data sets? And if not, how do you ensure that the homogeneity is good enough to use it for LTC?

Reply: We thank the reviewer for making this comment. The quality of the meteor radar measurements depend on the quality of the phase calibration to determine the angle of arrival, the accuracy to estimate the Doppler velocity from the ambipolar diffusing meteor trails and the range calibration of the system. However, the most crucial problem could be a phase drifting of the interferometer, thus, the phase calibration and phase stability monitoring is the most critical part.

Range calibration: The Juliusruh and Andenes MR were frequently range and power calibrated using a delay line feeding an attenuated transmitter pulse into the receivers and measuring a well-defined delay. The CMOR radar is cross calibrated by comparing optical trajectory solutions from camera systems with the individual radar meteors. Further, it is possible to use the time of flight solution without any range measurement as independent validation.

Doppler measurements: The Doppler measurement is less prone to measurement errors compared to the other two potential error sources as we use always the same software to estimate the radial velocities. Potential degradations in the local oscillators are compensated as the doppler measurement of the IP and QP voltages is always generated from the signal that was used in the transmission signal synthesis.

Phase calibration: The standard SKiYMET software runs, on a user defined frequency, an internal relative phase check to identify a possible degradation between the different receiver channels of the interferometer. Further, the Juliusruh and Andenes MR were 2 times per year maintained and all antennas/cables were controlled for potential phase mismatches and corrected. Further, we track the position for the major meteor showers throughout the year between all systems and check for potential mismatches.

The CMOR radar is also well-maintained and provides a detailed log file. In addition, the CMOR data can be cross validated by the other three frequencies and the optical

meteor observations. The CMOR meteor shower catalogue is also cross validated to optical observations.

- Page 5, lines 5ff: Here you describe the usage of triple frequency observations for the CMOR radar. It would be nice to have more details on the homogenization technique and how you compiled the data set.

Reply: Homogenization of multiple frequency datasets (Juliusruh 32.55 MHz and 53.5 Mhz, CMOR 17 MHz, 29 Mhz and 38 Mhz) are compiled on the basis of individual specular meteor trail measurements. The SKiYCORR software collects and reduces the data separately and provide a measurement summary containing the information for each individual meteor measurement such as radial velocity, radial velocity error and angle or arrival, time of detection and some other parameters.

Each radar provides an independent measurement for each meteor, although it is possible that the same meteor is detected at the different frequencies. All quality-controlled meteor detections are weighted by their statistical uncertainty and enter the wind analysis described in Stober et al., 2018.

Before we compile the multi-frequency combined wind data sets we run cross validations for each frequency and compare and cross-validate all systems for consistency. This is done for the CMOR data set as well as for the Juliusruh data set as long as multiple frequency observations were available. The Andenes MR is cross-validated and compared on a campaign basis to other Scandinavian meteor radars.

We added a subsection called “Homogenization of time series” to the manuscript: (for the last two remarks): The instruments used in this study were operational for almost two decades and some meteor radars did undergo substantial maintenance and modifications on the hardware. Most crucial for the wind measurements are the phase calibration and stability, the range sampling and the Doppler measurement.

The Andenes and Juliusruh meteor radar were maintained twice a year including a

test of the phase match of the cables and antennas. Further, the SKiYCORR software runs a phase test and provides a summary file of the impedance for each channel and day indicating potential problems. In addition, to the regular maintenance the CMOR meteor radar interferometry (phases) is cross validated to optical observations. In particular, meteor showers are monitored with CMOR throughout the year providing another source of information on the phase stability. The Andenes and Juliusruh meteor radar were also checked and cross validated using selected meteor showers during the course of the year.

Both European meteor radars were frequently range and power calibrated using a delay line (Latteck et al. 2008, Stober et al. 2010). The CMOR radar is also routinely checked for potential issues in the range sampling applying various cross calibrations. All systems used the same software package over the complete time span to derive the Doppler velocities to avoid artefacts due to changes in the parameter estimation (e.g., Doppler velocity or the velocity uncertainty).

Before the multi-frequency data sets for CMOR and Juliusruh are compiled, we analyze the winds for each frequency independently and cross-validate the resultant time series. If one instrument shows systematic issues in the wind time series compared to the other instruments and the climatology, this data is flagged and no longer considered in the finally compiled and merged wind time series. The Andenes meteor radar data is campaign wise cross-validated with other meteor radars in Norway.

References : Latteck, R., Singer,W., Morris, R., J., Hocking,W., K., Murphy, D. J., Holdsworth, D., A., and Swarnalingam, N.: Similarities and differences in polar mesosphere summer echoes observed in the Arctic and Antarctica, Annales Geophysicae, 26, https://doi.org/10.5194/angeo-26- 2795-2008, www.ann-geophys.net/26/2795/2008/, 2008.

Stober, G., Jacobi, C., and Keuer, D.: Distortion of meteor count rates due to cosmic radio noise and atmospheric particularities, Advances in Radio Science, 8, 237–

241, https://doi.org/doi:10.5194/ars-8-237-2010, https://doi.org/10.5194%2Fars-8-237-2010, 2010.

- Page 6, lines 16-18: Here I suggest to either proof that there is no phase delay/direct physical causality (with e.g. an appropriate literature study) or just say that you do not use the F10.7 proxy. But for clarification, I would prefer the first propose. Otherwise this sentence sounds a bit too speculative.

Reply: We added some literature pointing out the complexity and diversity of the coupling and correlation between solar proxies and MLT winds. It appears to be a very controversial issue. However, we also looked into the possibility of potential phase delays between solar activity (F10.7 or sunspot number) and geomagnetic indices and solar wind. Kilcik et al., 2017 computed potential phase delays between the different indices. This delays could be months to years. However, it is beyond this study to investigate in detail, which may would get the highest correlation in the regression model. Further, we now added all phase information to the climatologies and the solar cycle forcing with season. This was also recommended by the second reviewer.

We modified the text into: The LTC and solar cycle effect are derived by using a linear trend model plus an 11-year oscillation, which is not tied to the F10.7 solar radio flux or the sunspot number. Qian et al. (2019) analyzed WACCM-X and wind observations above Collm (51°N, 13°E) and found that the wind signature is less statistical significant than the temperature response to the solar radio flux. Other studies exploring the stratospheric/tropospheric response to solar forcing indicate a more clear dependence (Rind et al., 2008; Salby and Callaghan, 2006; Lu et al., 2017) on solar activity. At the MLT, the wind seems to be less directly influenced by the F10.7 or sunspot number. Pokhotelov et al. (2018) found almost no correlation between the occurrence of mesospheric echoes at mid-latitudes and the solar radio flux (F10.7), but a clear dependence on the occurrence of these echoes due to meridional winds. Further, Stober et al. (2014) investigated the neutral air density response during the solar cycle 23 and found a phase delay of almost 1 year between the F10.7 proxy and the neutral air

density variation. [. . .]

Qian, L., Jacobi, C., and McInerney, J.: Trends and Solar Irradiance Effects in the Mesosphere, Journal of Geophysical Research: Space Physics, 124, 1343–1360, https://doi.org/10.1029/2018JA026367, https://agupubs.onlinelibrary.wiley.com/doi/abs/10.1029/ 2018JA026367, 2019.

Rind, D., Lean, J., Lerner, J., Lonergan, P., and Leboissetier, A.: Exploring the stratospheric/tropospheric response to solar forcing, J. Geophys. Res., 113, D24 103, https://doi.org/10.1029/2008JD010114, 2008.

Salby, M. L. and Callaghan, P. F.: Influence of the Solar Cycle on the General Circulation of the Stratosphere and Upper Troposphere, Space Science Reviews, 125, 287–303, https://doi.org/10.1007/s11214-006-9064-3, https://doi.org/10.1007/s11214-006-9064-3, 2006.

Lu, H., Gray, L. J., White, I. P., and Bracegirdle, T. J.: Stratospheric Response to the 11-Yr Solar Cycle: Breaking Planetary Waves, Internal Reflection, and Resonance, Journal of Climate, 30, 7169–7190, https://doi.org/10.1175/JCLI-D-17-0023.1, https://doi.org/10.1175/ JCLI-D-17-0023.1, 2017.

- Page 7, line 12: What is the reason of choosing a window size of 5 days in regard to obtaining the mentioned climatologies?

Reply: The 5 days are a mistake, we actually applied a 30 day window centered at the appropriate day to make our climatologies comparable to monthly means, which are often used in other studies.

We removed this part to avoid misunderstandings.

- Page 8, line 32: Can you give an explanation for this observation at CMOR (strongest maximum and mean amplitudes)?

Reply: Currently, we cannot given an explanation why such a strong enhancement of

the diurnal component takes place at CMOR, which further only occurs in the zonal component, and mainly during the winter. Additionally in Figure 7, an enhancement in the years 2002-2005 can be observed. Furthermore, this enhancement does not take place in the dominant semidiurnal component. Probably in a future work, with the help of GCMs, we are going to investigate why the zonal diurnal component results in such strong maximum and mean amplitudes.

- Page 11, lines 1-2: This sentence is not clearly understandable. Maybe the verb "modified" is a bit misleading here.

Reply: Thank you for the comment.

We changed the phrase into: The amplitudes of semidiurnal tidal components range between 3 and 6 m/s.

Technical corrections: - Regarding the notation, if units of physical quantities are in the denominator, contain numbers, and are abbreviated, they should be formatted with negative exponents. Consider correcting this in the whole manuscript.

General reply: We appreciate and adopted the comments regarding the technical corrections.

- Page 1, line 1: "...report on long-term..." - Reply: we corrected the word

- Page 2, line 13: Please correct: "spatial extents" - Reply: we corrected the word

- Page 3, line 15: Please correct: "the GW residual" - Reply: we corrected the word

- Page 4, line 29: For those who are not familiar with a "7-bit Barker code" can you explain and/or give a reference? -Reply: we added a reference (Hocking et al., 2016)

- Page 7, line 15: The structure of the sentence "Only during the fall transition..." has to be improved. It does not sound correct. -Reply: we changed the sentence into: During the fall transition, Juliusruh show for a month at altitudes above 95 km westward directed wind.

- Page 8, lines 2-3: The meaning of "... and periods of a few years" is not clear to me in this sentence. Please try to improve this. -Reply: we removed the sentence.

- Page 8, line 21: Maybe change the expression "seems to" to "is decreasing" in order to be more precise. Or are you unsure about this decrease. What about the uncertainty in this case? -Reply: we changed the phrase into “is decreasing”

- Page 9, line 31: Please correct: "...are indicate" to "are indicating" or only "indicate". - Reply: we corrected phrase into “indicate”

- Page 10, line 31: Probably there is an "and" missing in between "...during after...". - Reply: corrected

- Page 12, line 32: Correct: "MR are show" to e.g. "MR show". - Reply: thanks for the comment

- Page 13, line 9: Delete "the" after "Although". - Reply: thanks for the comment

- Figure 6: There is space to increase the label sizes for better readability -Reply: we increased the font size

Please also note the supplement to this comment:
https://www.ann-geophys-discuss.net/angeo-2019-51/angeo-2019-51-AC1-supplement.pdf

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