Anonymous Referee #2

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Wuhan Atmospheric Radio Exploration (WARE) Radar: Implementation and Initial Results By Chen Zhou, Haiyin Qing, Gang Chen, Xudong Gu, Binbin Ni, Guobin Yang, Yuannong Zhang, and Zhengyu Zhao

The manuscript presents initial and selected results of the Wuhan Atmospheric Radio Exploration (WARE) Radar. The authors provide a motivation of the research they plan to conduct with the system and demonstrate the capabilities of the radar by showing data from the troposphere up to the mesosphere. However, the different scientific aspects are rather short. The citations given by authors are more or less a very short summary of what has been done 20-30 years ago and some recent advances with other MST radars seem to be not discussed. Reading the manuscript leads to the impression that there are many different aspects presented, but they are not discussed and threated as it should be done. Each of the presented scientific sections requires further analysis and the presented results should be related in more detailed to more recent papers in those fields. Further, there is a remarkable amount of language mistakes that require a careful language editing. The number of mistakes is too numerous to be listed in the review.

We would like to thank the reviewer for the constructive and valuable comments, which help to greatly improve the quality of the present paper.

According to the reviewer's comment, we have gone through a more detailed investigation on the basic radar information and scientific discussions. We also realize the reviewer's concern on the merit of this study. We agree with the reviewer that the experimental results by MST radars reported in this paper is not new. We would like to draw the reviewer's attention that it is an important addition to current knowledge that we have followed this mature technique and constructed for the first time the MST radar system at Wuhan in China with reasonably validated results, which can act as a useful ingredient of the global ground-based network of studying the properties of the atmosphere and the

ionosphere. As more and more WARE data are collected for accumulation, comprehensive analyses, either a case study, multi-event study or statistical survey will be conducted with expectation of more findings as of the regional atmospheric characteristics in mid-latitude China.

We hope that reviewer is satisfied with our responses and revisions and we look forward to hearing from you soon.

Major scientific comments:

Concerning section 2:

This section contains the basic information about the radar system and the authors demonstrate the enthusiasm working with the radar system. The description and technical aspects of the radar are rather short and lack some interesting information that is of relevance for the later conclusions of the authors. Does the system have inferometric capabilities? What are the experiment settings for the tropospheric and mesospheric modes e.g. PRF, range resolution, pulse coding etc.? Do the authors estimate the radial wind velocities applying additional coherent or incoherent integrations? Can the system perform multi-beam experiments (sequential or parallel)? How many different beams are included in a single experiment? How many data points are recorded or what is the temporal resolution of the derived winds or power profiles? This information is of importance to the reader as they support the conclusions drawn by the authors. The number of coherent and incoherent integrations is of relevance on the quality of spectral information and is important to understand the altitude coverage of the system. Also the experiment settings contain helpful information about likely range aliasing effects and so forth, which could be one reason why they manipulated Figure 2.

Response:

We appreciate the reviewer for raising these valuable comments and suggestions. The system configuration and radar parameters have been presented in detail in [Zhao et al., 2013]. Therefore, in this paper, we just demonstrated a

concise description of WARE radar system and its main parameters. However we agree with the reviewer that sufficient information should be provided to the reader for better understanding the scientific results. We have followed the reviewer's suggestion that some important specifications are added to Table 1 in the revised manuscript, such as pulse width, IPP, numbers of CI and FFT in low, medium and high operational modes.

A point by point response is as follows:

Does the system have inferometric capabilities?

Response:

WARE radar does not have the infermetric capability in current stage. Doppler beam swinging method are utilized for wind measurement.

What are the experiment settings for the tropospheric and mesospheric modes e.g. PRF, range resolution, pulse coding etc.?

Response:

The PRF of low, medium and high mode is 6250 Hz, 3125 Hz and 781 Hz; range resolution is 150 m, 600 m and 1200 m. The pulse coding is 4 bit complementary code for low and medium mode, 8 bit for high mode. The specification of PRF, pulse width and pulse coding of different modes are presented in Table 1 in the revised manuscript.

Do the authors estimate the radial wind velocities applying additional coherent or incoherent integrations?

Response:

Yes. Coherent and incoherent integrations are applied for the wind velocity estimation. Coherent integration number for three mode is 128 (low mode), 64 (medium mode), and 8 (high mode). Incoherent integration number is 10 for all modes. Please see Table 1 in the revised manuscript.

Can the system perform multi-beam experiments (sequential or parallel)?

Response:

Yes. WARE radar have five beams, which is north, south, west, east and horizontal, which are on operation in sequence.

How many different beams are included in a single experiment? How many data points are recorded or what is the temporal resolution of the derived winds or power profiles?

Response:

For one entire wind experiment, five different beams are included. Data point for low and medium mode is 2560, for high mode is 4096. The temporal resolution is approximate 52 second for one single beam.

Section 3:

The authors compare the winds derived from their DBS observations to rawinsonde data. How many rawinsonde flights were conducted? How far did the rawinsonde drift away from the radar? Are there some mountain ridges close to the radar site that can generate mountain waves? See discussion of recent wind comparison (Lee et al., 2014, NERC Aberyswth) or MAARSY (Stober et al., 2011)? Why did the authors use 20 ° off-zenith beams for the mesospheric wind observations? This leads to a huge observation volume and the wind observation becomes more complex (e.g. Browing and Wexler 1967, Waldteufel and Corbin 1973, Stober et al., 2014, AMT). To get a 'good' wind estimated from such a huge volume at least the horizontal divergence should be included. Are the discrepancies in Figure 1 related to orography or to the increasing distance between the rawinsonde and the radar? The authors did definitely manipulate Figure 2 by including a rectangle of constant contour level between 76 - 81 km altitude and a Doppler shift between 25-50 m/s. The reviewer encourages the authors to show the data as it is. They should discuss why they did not take into account this part of the spectrum or show a different example rather than changing the Figure. The shown data on tropopause heights needs also some further analysis. I hardly can see the tropopause height from Figure 3. This should be discussed in much more detail. The reviewer also *misses a comment; Why is the tropopause height of importance?*

Response:

We thank the reviewer for raising the helpful comments and suggestions. Let me answer your questions point to point.

How many rawinsonde flights were conducted?

Response:

We have conducted 10 flights to compare the rawinsonde and radar results.

How far did the rawinsonde drift away from the radar?

Response:

The maximum distance of rawinsonde recorded is about 2 km. We use the maximum 20 ° off-zenith beams for radar wind estimation to get an average wind profile.

Are there some mountain ridges close to the radar site that can generate mountain waves? See discussion of recent wind comparison (Lee et al., 2014, NERC Aberyswth) or MAARSY (Stober et al., 2011)?

Response:

We appreciate the reviewers for providing these informative and valuable references. The WARE radar is located at the Jianghan Plain, no large mountain ridges are close to the radar site. Small uncontinuous foothills are located about 50 km south of the radar, which could produce mountain lee waves. We agree with that these potential waves could induce uncertainties in radar wind measurement [Lee et al., 2014]. However, more rawinsonde tests should be conducted to investigate the influence of the mountain waves on the WARE radar. Heartfelt thanks to the reviewer for this important comments. Please see Lines 137-141 in the revised manuscript.

Why did the authors use 20 ° off-zenith beams for the mesospheric wind observations?

This leads to a huge observation volume and the wind observation becomes more complex (e.g. Browing and Wexler 1967, Waldteufel and Corbin 1973, Stober et al., 2014, AMT). To get a 'good' wind estimated from such a huge volume at least the horizontal divergence should be included.

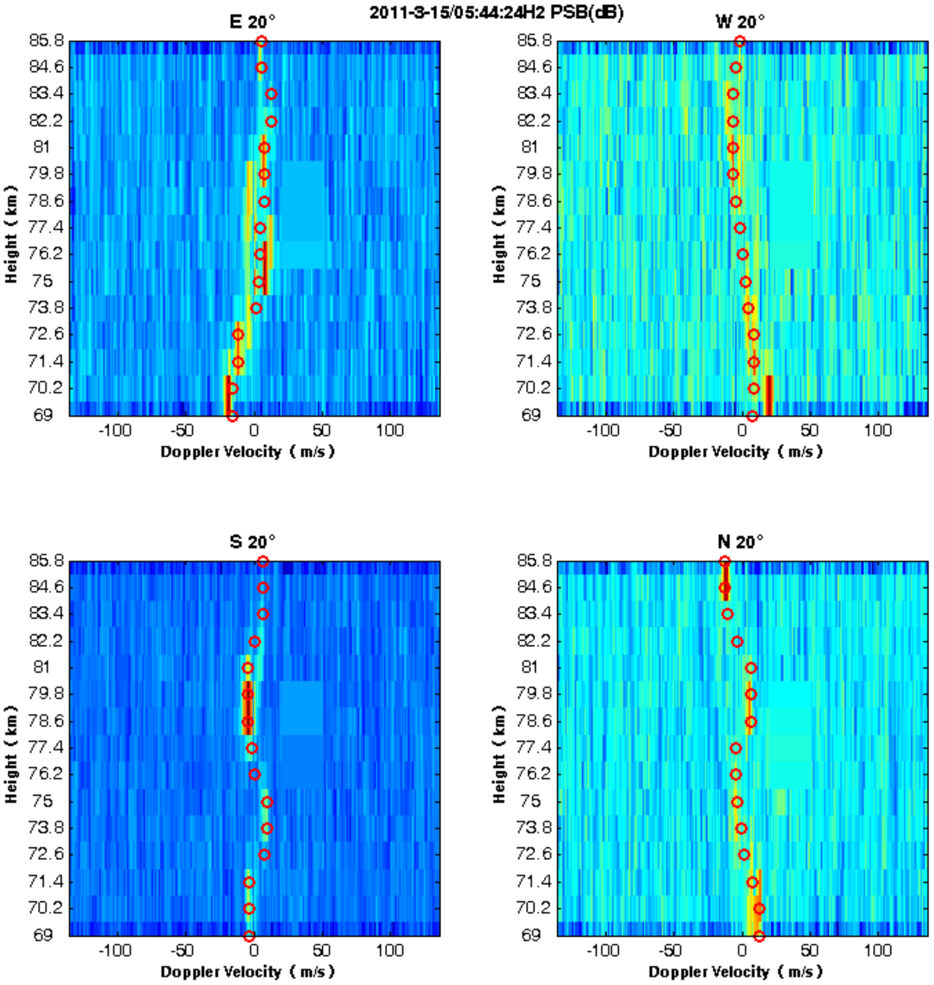
Response:

We appreciate the reviewer for this valuable and important comments. We use the 20 ° off-zenith beams for the mesospheric wind and would like to cover a vast horizontal area and get enough horizontal wind velocity component. However, these measurement need more homogenous backscatter in the observation volume [Stober et al., 2013]. We have add the discussion in this section to inform the reader about this uncertainties. Please see Lines 131-135 in the revised manuscript.

The authors did definitely manipulate Figure 2 by including a rectangle of constant contour level between 76 - 81 km altitude and a Doppler shift between 25-50 m/s. The reviewer encourages the authors to show the data as it is. They should discuss why they did not take into account this part of the spectrum or show a different example rather than changing the Figure.

Response:

We appreciate the reviewer for point out this defect in Figure 2. To be honest, we did not manipulate this figure on purpose. This rectangle could be some data missing or NaN during radar data processing. Below is the original figure plotted by raw data, we just zoom in the Doppler velocity to -50-50 m/s to make the Doppler shift more obvious. The height resolution is 1.5 km at this mode.



The shown data on tropopause heights needs also some further analysis. I hardly can see the tropopause height from Figure 3. This should be discussed in much more detail. The reviewer also misses a comment; Why is the tropopause height of importance?

<u>Response:</u>

We thank the reviewer for raising this helpful comment. The tropopause have been considered as an important role in understanding a vast of atmospheric processes such as stratosphere-troposphere exchange and global circulation. For midlatitude tropopause, it could also be a local source for IGWs. Because tropopause is acting as a source region for much of the air entering the stratosphere. The height of tropopause is very important. The location of tropopause can be different according to different tropopause definitions and

tropopause dynamics [Yamamoto et al., 2003; Das et al., 2008]. In addition, the tropopause is not just a thin layer but a transition region between the troposphere and stratosphere [Mehta et al., 2008]. Figure 3 demonstrate the difference between the cold point tropopause (CPT) from rawinsonde and radar tropopause.

Yamamoto, M. K., M. Oyamatsu, T. Horinouchi, H. Hashiguchi, and S. Fukao, High time resolution determination of the tropical tropopause by the Equatorial Atmosphere Radar, Geophys. Res. Lett., 30(21), 2094, doi:10.1029/2003GL018072, 2003.

Das, S. S., A. R. Jain, K. K. Kumar, and D. Narayana Rao (2008), Diurnal variability of the tropical tropopause: Significance of VHF radar measurements, Radio Sci., 43, RS6003, doi:10.1029/2008RS003824.

Mehta, S. K., B. V. Krishna Murthy, D. N. Rao, M. V. Ratnam, K. Parameswaran, K. Rajeev, C. S. Raju, and K. G. Rao (2008), Identification of tropical convective tropopause and its association with cold point tropopause, J. Geophys. Res., 113, D00B04, doi:10.1029/2007JD009625.

Aspect sensitivity: The section of the aspect sensitivity is completely misleading. The authors mainly refer to rather old publications and ignoring the recent possibilities of the new systems and the advances that have been done. The examples shown in Figure 5 are not suitable to discuss this issue. Aspect sensitivity requires a much more detailed analysis and should not be inferred from a single measurement. Usually long averaging times are required to get rid of random effects. How can the power become larger with increasing off-zenith angle? This is against the complete theory of aspect sensitivity - maybe the concept is wrong or incomplete? Did the authors check the mean angle of arrival? Maybe the beam volume was not completely filled? Typical MST 'scatterers' are patchy, viz. the assumption of complete volume filling is not always satisfied.

<u>Response:</u>

We appreciate the reviewer for this important comments. We totally agreed with the reviewer that statistical analysis could identify the significant feature of

the atmospheric aspect sensitivity and remove the incorrect and random data point. Study of aspect sensitivity can yield a deeper understanding of the mechanisms of the atmospheric radar echoes, like isotropic/anisotropic turbulence or Fresnel reflecting/scattering structures. However, it is difficult to separate the respective contributions of these echoing mechanisms. In this case, we present irregular pattern of aspect sensitivity at six specified heights of troposphere and low stratosphere, which could be an evidence for the complicated interpretation of atmospheric aspect sensitivity and that combined mechanism could make contributions. We also agree with the reviewer that echoes could be come from different scatters, especially at low beam angles. Tsuda et al. [1997] suggest that horizontal component of atmospheric gravity wave motions could distort the refractivity surface. This mechanism could also contribute to the inconsistency of our result to the regular pattern.

We have rewritten this section and discussed the interpretation. Please see Lines 248-258 in the revised manuscript.

Tides: The reviewer was not aware that atmospheric tides can be found in the troposphere at least with fairly reasonable amplitudes. As far as I know the diurnal tide is generated in the troposphere by water vapor and the semi-diurnal tide the stratosphere by ozone, but for both tides the amplitudes increase with altitude and become dominant modes in the mesosphere. A closer inspection of the lomb-scargle spectrum shown in Figure 7 indicates a significant offset from 12 and 24 hours. The peaks show a period of 12.3 and 24.5 hours, which is far outside of what I would expect to be a tide. I expect that the tropospheric winds are dominated by synoptic processes as fronts and high and low pressure systems. The authors should discuss those points.

Response:

We appreciate the reviewer for this valuable comments. Tidal horizontal wind amplitudes can reach to several tens of m/s in mesosphere and low thermosphere, which have been intensively studied for thirty years. However, due to the weak amplitude, tides in troposphere and lower stratosphere have not been subjected to

sufficient study. Recent research with intense rawinsonde and radar measurement [Whiteman et al, 1996; Huang et al, 2009; Sakazaki et al, 2010] have presented tidal wind perturbations in tropospheric and low stratospheric data. However, due to nonlinear wave-flow and wave-wave interactions, tidal frequency spectral estimation could be biased with periods around the diurnal and semi-diurnal tides.

C. David Whiteman and Xindi Bian, 1996: Solar Semidiurnal Tides in the Troposphere: Detection by Radar Profilers. Bull. Amer. Meteor. Soc., 77, 529–542.

Huang, C. M., Zhang, S. D., and Yi, F.: Intensive radiosonde observations of the diurnal tide and planetary waves in the lower atmosphere over Yichang (111°18' E, 30°42' N), China, Ann. Geophys., 27, 1079-1095, doi:10.5194/angeo-27-1079-2009, 2009.

Sakazaki, T., M. Fujiwara, and H. Hashiguchi (2010), Diurnal variations of upper tropospheric and lower stratospheric winds over Japan as revealed with middle and upper atmosphere radar (34.85°N, 136.10°E) and five reanalysis data sets, J. Geophys. Res., 115, D24104, doi:10.1029/2010JD014550.

However, the reviewer sees a great potential for the authors to perform high quality contributions to the scientific fields that they touched in this paper. In particular, the presented AGW analysis shows the high quality of their work and skills as well as the power of the radar. The tropospheric wind measurements show the great potential of the WARE radar to be used for AGW studies in that altitude region.

Response:

We thank the reviewer for the positive comment. A statistical analysis of the IGWs observed by WARE radar has been recently reported by Qing et al. [2014]. By analyzing the statistical 3-D wind field in troposphere, the results indicate that seasonal variations are related to the varying importance of these IGW sources. However, in that paper, we did not consider too much about the orography which

could also be a factor to produce atmospheric waves. As more data are cumulated, we could investigate the problem with more comprehensive insights and understanding.

Again, we thank the reviewer for the careful examination of the manuscript and the valuable comments on the manuscript, which put this paper into a more suitable shape.