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Responses (highlighted with red) to Referee#2
14 Oct. 2022

General comments:

This study presents the advanced WISSDOM synthesis scheme that can provide high- resolution three-dimensional wind fields in clear weather, which was only available in storms before. The authors examined the performance of the wind retrieval from the advanced WISSDOM in a strong wind case over complex terrain. The mean biases are generally small, demonstrating that the new WISSDOM is capable of providing reliable wind fields in fair weathers and topography. Several sensitivity tests are also performed to determine the optimal settings of the new WISSDOM system.

The manuscript is organized and well-written. The figures are well illustrated. Yet, there are some issues that need to be clarified and addressed before publication.

We appreciate Referee#2 providing helpful and insightful comments, which help us to improve the manuscript substantially. A set of responses to your comments is provided below. Specific locations of modified portions (marked as underlines) were also noted as the number of lines in the revised manuscript.

Specific comments

1. The authors quantify the sensitivity tests and discuss these tests respectively in table 2 and Figs. 6 and 9. Yet, these only state the number of the biases but without further discussions. Having some more discussion and a summarized recommended recipe in conclusion would be more helpful for the future users, e.g. what observations are the most critical in some cases, how to determine the related RI/VE, and why these suggestions may work (e.g. the height of the PBL, decorrelation of the atmospheric state based on observations, etc.).

Thank you for this valid point. Significant discrepancies can be found without some inputs like the AWS and Lidars. More discussions about the importance of each input have been added in the last paragraphs in 5.1. Please check these parts as below:

<u>L611-616. The wind speed can be better modulated in modified version of WISSDOM when the Doppler lidar observations were adopted. These results also implied that the ranges of errors are relatively small when we try to evaluate the discrepancies between the control run and each independent observation. In summary, the results of this experiment (cf. Fig. 13) concluded that the lidar and AWS data are more critical inputs in modified WISSDOM, and it will be benefits if more inputs can be included.</u>

Since the average distance between each AWS site is from ~100 to 2000 m, and the main purpose of the modified WISSDOM is trying to include more and complete data. Therefore, the setting of this sensitivity testing is from 0.5 to 2 km in horizontally and from the default setting (50%) to extending setting (90%) in vertically. The conclusions, main reasons how to determine the setting of RI/VE, and more discussions have been modified for clearly as:

L623-626. There were five designs (B-1~B-5) in Experiment B with the ranges of RI (VE) between 0.5 km (50%) and 2 km (90%). Because the average distance between each AWS site is approximate from 0.1 to 2 km and more data can be included in vertically.

L661-665. The conclusions indicated that the moderate setting (i.e., RI is 1 km) will be helpful to get the smallest differences with the control run. In addition, the wind directions and speed should be more dominated by terrains at lower layers, the implements of AWS data are very important for the modified WISSDOM synthesis, especially at the height below 900 m MSL.

- Why is the average bias higher between WISSDOM-lidarQVP than between WISSDOM- sounding?

  First, the sounding data have been adopted in WISSDON following its tracks; second, the QVP were made via more dense observations at lower layer but not higher layer. Therefore, the results of WISSDOM synthesis are in good agreement with the sounding for each level and with QVP only at lower layers. The descriptions and explanations have been emphasized for clearly as:

  L210-211. The sounding data in J_6 were interpolated to the given grid points near its tracks bearing on the radius influence (RI) distance (the details are provided in Section 3.2.3).

  L448-449. Fig. 6 shows the scatter plots of the u- and v-component winds on the locations following the tracks of sounding launched from the DGW site.

  L528-532. In summary, the discrepancies in the 3D winds between the WISSDOM synthesis and lidar QVP were small in the lower layers and large in the higher layers because the observational data from lidars and AWS provided good quality and sufficient wind information at the lower layers but not in the higher layers (lower coverages of lidar data above 1.3 km MSL, cf. Fig. 4).

- Why is v-component correlation of WISSDOM-lidarQVP particularly lower (down to 0.38)?

  Following our responses above, relatively less data from lidar QVP were adopted at higher layers. We have calculated the correlation coefficients below 2 km height MSL, and the results shows higher correlation (~0.45). The descriptions have been added in the texts as:

  L501-504. The correlation coefficient of v-component winds is lower (0.35) in association with low wind speed (<15 m s^{-1}) from the surface to 2.5 km MSL (Fig. 9b), and it may possibly relate to less coverages from lidar QVP data at higher layers.

- In addition, what sensitivity tests do the authors suggest readers must do based on your experiences if they are interested in applying the WISSDOM system in different terrains and the weather systems (e.g. typhoons, land-sea breeze etc.)?

In our case, reasonable winds can be derived over complex terrain when the VE was set as 90%. We would like to recommend that 90% (50%) of VE should works well over complex terrain (flat surface) in modified WISSDOM. Lidar is good tool to derive the winds, it will be useful to apply the modified WISSDOM in the analyses of land-sea breeze, low-pressure system without precipitation, micro-downburst, and any meteorological phenomena under clear-air conditions. The descriptions have been added in the manuscript as:

L752-754. In addition to the reasonable winds can be derived by applying the optimal setting in modified WISSDOM, 90% (50%) of VE are also recommended over complex terrain (flat surface).

L767-769. Except for the detailed wind structures can be well documented in any meteorological phenomena under clear-air conditions (eq., land-sea breeze, micro-downburst, and non-precipitation low-pressure systems etc.).

2. Sec. 3.2.1 and 3.2.2 Why use the interpolated observation data in the Cartesian coordinate instead of the original high-resolution observations of scanning Doppler lidars and AWS? Why use the lidar QVP instead of the high resolution lidar information?

Usually, the most efficient way to minimize the cost function is to use Cartesian coordinate for partial differential equation (Armijo, 1969). Besides, the default setting of original WISSDOM were performed on Cartesian coordinate as well (Liou and Chang, 2009). Thus, we performed the variational calculations on the Cartesian coordinate in modified WISSDOM in this study. Based on this, we were finally interpolated any input data (including the lidars and AWS) to Cartesian coordinate here. The descriptions about these statements have been added in the revision clearly as:

L268-273. Although relatively dense and complete coverage of wind information (i.e., radial velocity of aerosols) were sufficiently recorded by lidar observations, the collected data are usually not located directly on the given grid points in the WISSDOM synthesis (i.e., Cartesian coordinate system). In this study, the lidar data were interpreted simply from the lidar coordinate system to the Cartesian coordinate system via bilinear interpolation.

L348-350. The Cartesian coordinate is the most efficient way and the best system for partial differential equation (Armijo, 1969), then it also be used in the cost function of WISSDOM (Liou and Chang, 2009).

3. In the evaluation of the control run, the observations used for evaluation are also used in the wind retrieval by WISDOM. Are there other independent observations that can be used for evaluations?

Since the basic idea of WISSDOM is variational-based scheme to minimize every constraint in cost function. The optimal results can be calculated when it included more data as possible. According to our responses to the same comments from Refee#1. We have emphasized that the retrieved winds from the control run are the optimal results (i.e., the analytic expression of variational-based scheme in

WISSDOM) in the texts as below:

L133-135. The 3D winds were derived by variationally adjusted solutions to satisfy the constraints in the cost function, thus the results of retrieved winds were the analytic expression in this scheme.

L395-397. Therefore, the retrieved winds from the control run can be treated as the optimal results (i.e., analytic expression of variational-based scheme) in WISSDOM.

4. Sec. 2.1: For the methodology:

- In fair weather, how are the radar reflectivity and radial velocity constrained in new WISSDOM? Do you use clear echoes or insects? Do you use both Z and Vr?

  In modified WISSDOM, only lidar radial velocity were used because there was no reflectivity can be detected by radar under clear-air conditions. In addition, we did not use any echoes and insects in modified WISSDOM since we assumed the terminal velocity of air mass are small and can be neglected. Thus, the terminal velocity of particle can be set to zero in eq. (3). The description can be found in:

  L200-204. Instead of the radial velocity $(V_r)_{i,t}$ observed from Doppler radars in eq. (3) in original version of WISSDOM, the radial velocity observed from Doppler lidars was adopted in the modified WISSDOM synthesis. In addition, if there were no precipitation particles under clear-air conditions, the terminal velocity of precipitation particles ($W_{T,t}$) was set to zero in eq. (3) in the modified WISSDOM.

- Why do the authors include the vorticity equation in the cost function? What are the advantages and disadvantages?

  The vorticity equation is not first applied in wind retrieval scheme, and Liou and Chang (2009) have also applied the vorticity equation in original version of WISSDOM. As the conclusions from above study, the main advantage is that the use of the vertical vorticity equation can provide further improvements to the winds and thermodynamic retrievals. The descriptions have been added in the text as:

  L190-192. Note that the main advantage is that the use of vertical vorticity can provide further improvement in winds and thermodynamic retrievals.

- What are the time steps in the 4DVAR system of WISSDOM?

  We used 12 mins to be the interval between two time steps in our modified WISSDOM. It is because the temporal resolution of main input lidar data is 12 mins. The descriptions about these have been added in the text for clearly as:

  L204-206. The time steps in WISSDOM of this study were set by the synthesis time and 12 mins before the synthesis time due to the temporal resolution of main input lidar data is 12 mins.

Minor comments:

1. L 60: It will be helpful to specify what weather systems.

The specific weather systems have been indicated in the text in:

L46-50. Most comprehensive applications of the derived winds were adopted to document kinematic and precipitation structures associated with various weather systems at different scales like typhoon, tropical cyclone rainband, and non-precipitation low-pressure system (LPS) (Yu and Tsai, 2013, Yu and Tsai, 2017, Tsai et al. 2018, Yu et al., 2020, Cha and Bell, 2021, Tsai et al., 2022).

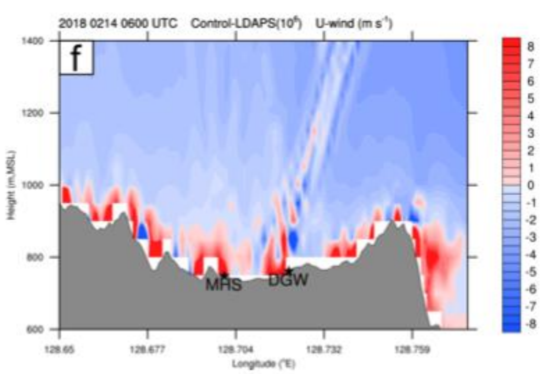
2. L 67-77: I'm not sure how the VTD/GBVTD/EGBVTD are related to the developing of WISSDOM system or three-dimensional wind retrieval. It's not clear. Please clarify it.

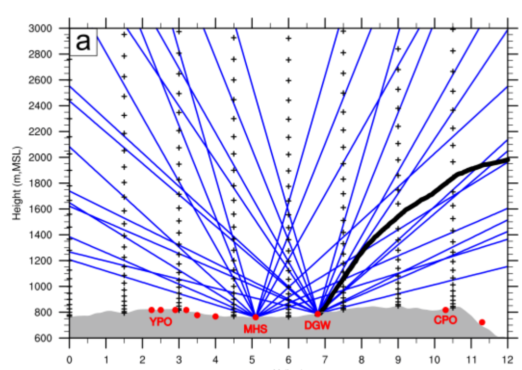
The reason why we mentioned those schemes in advance, because we are trying to emphasize the advantages of WISSDOM. The descriptions about the contexts and explanations have been added for clearly as:

L62-67. However, winds usually present nonuniform patterns and fast-evolving characteristics in most mesoscale weather systems and microscale phenomena, and complete and detailed winds are still difficult to resolve by these techniques. Based on the contexts of weaknesses from above schemes on the wind retrievals. Instead of a single Doppler radar, multiple Doppler can retrieve better quality 3D winds with relativity fewer assumptions because they provide sufficient radial velocity measurements and wind information with wider coverage in the synthesis domain.

3. Figure 16f: There is a very artificial band in Fig. 16f, the difference between the control run and the C3. Please explain the artificial pattern.

These artificial band (showing in the right figure below) are highly related to the sounding since its locations are almost the same with the track of raising sounding in this study (as Fig. 2a, thick black line, left figure below).





Technical issues:

1. L 153: The acronym of the time steps (t) and two time (t) steps are the same. It’s confusing.

The acronym has been removed for clearly.

2. L 290: gird → grid

Thanks for indicating the typo, and this typo has been corrected.

3. Figure 3. It will be helpful to indicate the location of the analyzed area on the synoptic surface map for readers who are not familiar with Asia.

The new figure has been replaced to emphasize the location of the Korean peninsula (as below), and the descriptions have been also added in figure captions.

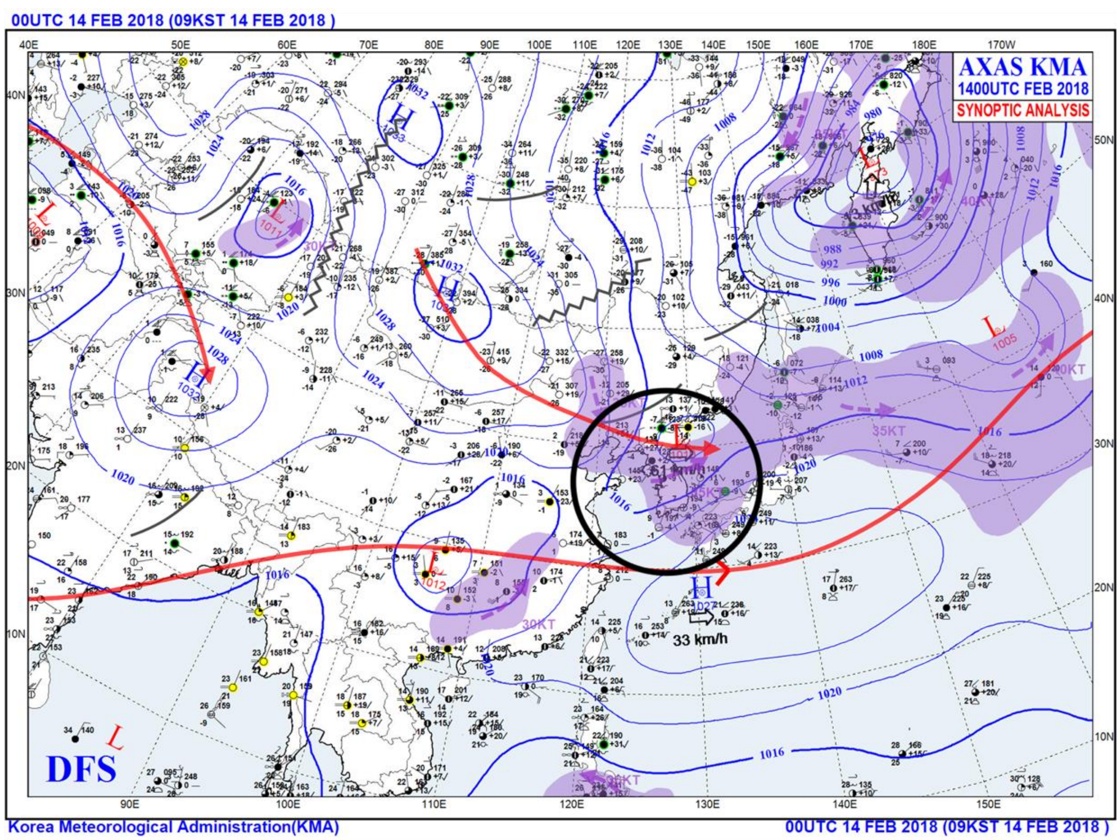


Figure 3. Synoptic surface chart from the Korea Meteorological Administration (KMA) at 00:00 UTC on 14 Feb. 2018. The locations of the Korean peninsula and the LPS has been marked by black circle.

Reference

Armijo, L.: A theory for the determination of wind and precipitation velocities with Doppler radars. J. Atmos. Sci., 26, 570–573. 1969.

Liou, Y., and Chang, Y.: A Variational Multiple–Doppler Radar Three-Dimensional Wind Synthesis Method and Its Impacts on Thermodynamic Retrieval. Mon. Wea. Rev., 137, 3992–4010, https://doi.org/10.1175/2009MWR2980.1, 2009.