Response to Referee 1 Comments

General comments:

1. This paper provides a comprehensive evaluation of the CMA-MESO model's ability to predict downward long-wave irradiance (DnLWI) in China, using extensive high time-resolution in-situ measurements. The study is significant as it identifies the model's performance under various atmospheric conditions and highlights discrepancies particularly under overcast, dry, and cloudless scenarios. The authors also pinpoint the influence of cloud cover and stable nocturnal boundary layer on the model's accuracy. This thorough assessment offers valuable insights for improving the radiation schemes in NWP models and underscores the importance of accurate cloud representation in enhancing model reliability. The manuscript is suitable for publication, once minor revisions are made.

Thank you for this comment, and we are grateful for reviewer's encouraging comments.

2. The title of the manuscript, "Evaluation of radiation schemes in the CMA-MESO model using high time-resolution radiation measurements in China: I. Long-wave radiation", is somewhat misleading. The study exclusively assesses downward long-wave irradiance (DnLWI), without addressing other aspects such as downward long-wave irradiance in specific atmospheric layer or upward long-wave irradiance. The authors can find their suitable words to clarifying this in the title would better reflect the manuscript's focus and scope. Probably, for instance, change "Longwave radiation" to "surface downward Longwave radiation".

Thank you very much for your valuable comments and suggestions.

Exactly, the title of the original manuscript is not very precise, and we would like to modify it to "Evaluation of surface downward long-wave irradiance forecasts from the CMA-MESO V4.1-V5.1 based on high time-resolution radiation measurements in China" in the revision of the manuscript.

Specific comments:

1. Line 132: "quality control". The pyrgeometer measurements are only valid within certain spectral ranges. Did this 'quality control' step consider the response function of the pyrgeometer? To validate the LW radiation scheme using in-situ pyrgeometer measurements, signals of DnLWI predictions from the CMA-MESO that are beyond the pyrgeometer's spectral range must be filter out. Did this 'quality control' step consider masking those signals?

Thank you for your mention of effects of the pyrgeometer.

Yes, we have considered the response function of the pyrgeometer before the 'quality control' step. As we all known the initial record of the pyrgeometer is voltage of the sensor, which is subsequently converted into the irradiance via multiplying the sensitivity coefficient of the pyrgeometer. The sensitivity coefficient, which is usually derived from calibration with the reference pyrgeometer, includes the effects of the response function of the sensor, the transmittance of the dome, etc.

Though the radiometers used in this study have spectral ranges of ~4.0 to 50.0 μm and the CMA-MESO model forecasts the DnLWI over a wider spectral range (10-3000 cm^{-1} or 3.33-1000 μm), most of the downward long-wave spectral irradiance emitted by the atmosphere presents within the spectral range of the pyrgeometer according to the Planck's law and the actual atmospheric temperature. Thereby, the portion of DnLWI predicted by the CMA-MESO outside of the spectral range (~4.0 to 50.0 μm) is generally negligible. Even so, we considered this effect to some extent via comparing the DnLWIs observed by the pyrgeometer with the theoretical DnLWI values, which are calculated in terms of the air temperature at 2 m height by using the Stephen-Boltzmann's law during the 'quality control' processing in this study.

2. Lines 161-162: "…… were taken as input parameters into the MODTRAN model", I wonder if the atmospheric profile inputs used to drive the RRTM in the CMA-MESO and MODTRAN are identical? So that comparisons between RRTM and MODTRAN are reasonable to be make.

Thank you for your vital comment.

It is true that the reasonability of comparison between DnLWIs simulated by the MODTRAN model and RRTM in the CMA-MESO model depends on the identical atmospheric profiles. It is worth noting that a height-based-terrain following coordinate proposed by Chen and Somerville (1975) is adopted in the CMA-MESO model (Chen et al., 2008). Specifically speaking, a total of 50 layers of air temperature and relative humidity (or specific humidity) at variable pressure level is used in the CMA-MESO model.

Although the 50-layer air temperature and relative humidity profiles are adopted by the RRTM in the CMA-MESO model, the air temperature and humidity profiles at 19 isobaric surfaces (1000, 975, 950, 925, 900, 850, 800, 750, 700, 650, 600, 550, 500, 450, 400, 350, 300, 200, and 100 hPa) were merely output by the CMA-MESO before 2022. We, thereby, used the output atmospheric profiles at 19 isobaric surfaces together with the background atmospheric profiles (with pressure lower than 100 hPa) to reconstruct the input atmospheric profiles, which were used to drive the MODTRAN model in this study.

To elucidate discrepancies between the original atmospheric profiles used in the CMA-MESO model and the derived atmospheric profiles adopted in the MODTRAN model, we selected five original/derived air temperature and humidity profiles at the XL site under various conditions in 2022 and then put them into the MODTRAN to simulate the DnLWIs. Basic descriptions of the selected cases at the XL site under clear sky, partly cloudy, and overcast conditions are listed in Table 1, and the air temperature and relative humidity profiles are also plotted in Figure 1.

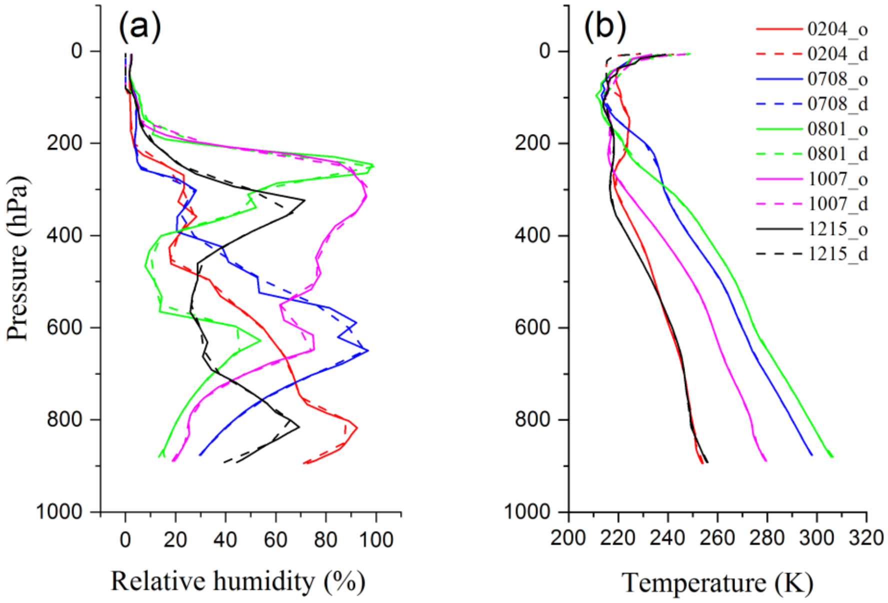

Figure 1. Original/derived atmospheric profiles of the (a) relative humidity and (b) air temperature input into the MODTRAN model for five typical cases at the XL site in 2022. Solid lines and “o” represent the original atmospheric profiles adopted in the CMA-MESO model and the MODTRAN model, and dashed line and “d” represent the derived profiles at the isobaric surfaces used in the MODTRAN model, which stemmed from the output profiles of the CMA-MESO model as well as the background atmospheric profiles.

It can be seen from Figure 1a that the derived relative humidity profiles are generally consistent with the original humidity profiles except that the formers are smoother than the latter at several layers (e.g., 700-500 hPa, etc.). The original air temperature profiles are identical to the derived ones except some negligible discrepancies occurred at the higher levels with the air pressure less than 100 hPa (Fig. 1b). Moreover, the relative deviation between the DnLWI simulated by the MODTRAN model using the original atmospheric profiles and the derived profiles ranges from 0.29% to 0.81% for five cases (Table 1), which gives us a lot of confidence that the comparison between RRTM and MODTRAN in this study is highly reasonable.

Table1. Basic descriptions of selected cases at XL site （54102） used to calculate the DnLWIs with the MODTRAN model.

No.	Time (UTC)	Sky condition	Cloud type	Cloud amount (%)	T_a (K)	Pa (hPa)	PWV (g cm^{-2})	Vis （km）	DnLWI_o (Wm^{-2})	DnLWI_d (Wm^{-2})	Relative deviation （%）
1215	2022-12-15T05:00	Clear sky	–	0	256.0	892.1	0.08	24.0	135.9	136.3	0.29
1007	2022-10-07T02:00	Partly cloudy	High cloud	55	279.6	888.7	0.54	24.0	222.7	224.5	0.81
0708	2022-07-08T10:00	Partly cloudy	Medium cloud	49	298.1	876.3	2.14	27.8	395.1	396.6	0.38
0204	2022-02-04T02:00	Partly cloudy	Low cloud	47	254.1	893.9	0.13	24.0	221.1	221.9	0.36
0801	2022-08-01T05:00	Overcast	High cloud	100	306.4	879.7	1.51	24.0	347.5	349.9	0.69

3. L324-331: Figures 2u-y show performances of various versions of the CMA-MESO model. Are there any possible reasons explaining the different performance across various versions of the CMA-MESO model? I recommend the authors to added 2-3 sentences (or probably more sentences) to simply elucidate this somewhere in the text.

Thank you for your valuable comments.

In revision of the manuscript, we added some relevant sentences as well as one reference citation to further elucidate the different performance across various versions of the CMA-MESO model.

"The RRTM scheme in the CMA-MESO model is almost unchanged among different versions, while other improvements in the model may affect its forecasting performance. For instance, improvements in boundary scheme, cloud microphysics scheme, and three-dimensional variational data assimilation system were involved during the evolution of the CMA-MESO version. On the other hand, the humidity field in the CMA-MESO V5.0 is still unstable though it has stable forecast performance with relatively small biases (Ma et al., 2022). The original semi-Lagrangian scheme to calculate the advection of water vapor in the CMA-MESO V5.1 was replaced by an improved material advection scheme, which leads to smaller dispersion and dissipation error in this version of the CMA-MESO model (Peng et al., 2022)".

4. L400-406: "……were replaced with ……the middle latitude summer, the middle latitude winter……" The 88 profiles predicted by the CMA-MESO are 3-h forecast field across 8 hours cycle per day. Right? The total inputs for MODTRAN include 33 layers, this first 19 layers are from CMA-MESO, the remaining 14 layers are from standard atmosphere (e.g., the middle latitude summer, … The tropical atmosphere). What are the rationalities for this treatment?

Thank you for your question.

In this study, the extraction method for all variables predicted by the CMA-MESO (e.g., the DnLWIs, the atmospheric profiles, air temperature at 2-m height, the surface pressure, etc.) is the same. In other word, the CMA-MESO starts forecasting at 12:00 UTC every day, and the later 24-h (12-35 h) hourly punctual forecasts (i.e., at 00-23 UTC on the next day) were selected to be further analyzed. Thereby, the 88 profiles are the randomly selected hourly instantaneous profiles from the later 24-h results predicted by the CMA-MESP that start forecasting at 12:00 UTC.

Previous studies indicate that as much as 60% (90%) of atmospheric emission is derived from the atmosphere within the first 100 m (1 km) under clear-sky conditions. When the sky is overcast, more than 90% originates from within the first 1 km between the ground and the bottom of the cloud (Ohmura, 2001). On the other hand, the CMA-MESO model using 50-layer atmospheric profiles in height-based-terrain following coordinates as an input profile, but it can only output the corresponding atmospheric profiles at 19 isobaric surfaces before 2022. In view of the DnLWI at surface is mainly influenced by the atmosphere within boundary layer, the atmospheric profiles at 19 isobaric surfaces output by the CMA-MESO and the background atmospheric profiles with pressure lower than 100 hPa were used to reconstruct the input atmospheric profiles to drive the MODTRAN model. In addition, the geographical position of the site and season were also considered during choosing the appropriate background atmospheric profiles (e.g., middle latitude summer, middle latitude winter, etc.).

In short, this treatment is highly trusted to be reasonable according to the test as described in the response to question 2.

5. Line 409-410: "clouds were transformed…" If clouds were predicted by the CMA-MESO (only 19 layers), how to present clouds for the remaining 14 layers? All were set to zero for the last 14 layers?

Thank you for your comment.

As mentioned previously (Line 401-402), the minimum pressure of atmospheric profiles in the first 19 layers is 100 hPa, which is approximately15-16 km apart from the ground and reaches the tropopause. As we all know almost all clouds occur in the troposphere, thus, it isn't necessary to present clouds for the remaining 14 layers (i.e., stratosphere and above layers) where the atmospheric water vapor content is very little and cloud is rarely to form.

To improve the accuracy of description, sentence in Line 416-418 is modified as "The cloud options input into the MODTRAN were set in terms of the cloud amount of the high-, medium-, and low-clouds predicted by the CMA-MESO model after matching the corresponding cloud types."

6. Line 521: "Figure 8. Spectral …..". Does the figure 8 represent a specific atmospheric layer? For the 2m height ? or does it integrate the entire atmospheric profile?

Thank you very much for your reminder.

Figure 8 represent the spectral absorption curves of the whole atmosphere, and the title of Figure 8 is modified as "Figure 8. Spectral absorption curves of the ***whole*** atmosphere that simulated with the MODTRAN model along with atmospheric profiles at the XL site for (a) case 1, (b) case 2, (c) case 3, (d) case 4, and (e) case 5. All absorbing gases and their spectral absorption bands are also denoted".

References

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