Response to the comments from Anonymous Referee#1

We thank the reviewer for his/her critical evaluation of the manuscript, as well as his/her valuable comments and suggestions. A point-wise reply to the comments from the reviewer is given below:

General Comment

The paper has been clearly improved. I still has some suggestions, most of them are minor points but three major issues remain. I still think that further English editing could improve the text. Examples are given as minor revisions below.

Reply: We thank the reviewer for carefully going through the revised version of the manuscript and giving useful comments and suggestions, as well as encouraging remarks.

Major Revisions

Comment 1: I am in doubt that z0 and zh are really the same in WRF. In this case the neutral Cd and Ch would be equal. But Figures 5(b) and (c) show that this is not the case.

Reply: We agree with the reviewer that the values of z_0 and z_h are not the same in the revised MM5 surface layer scheme available in the WRF model. In fact, in the model, the revised MM5 surface layer scheme uses a constant value of z_0, whereas the value of z_h is deduced from the expression suggested by Brutsaert (1982).
We sincerely apologise for the confusion created in the previous reply.

The text regarding this has been modified in the revised version of the manuscript and is presented here for reviewer's reference:

Lines 204-205…Moreover, the scheme uses constant values of z_0, while the values of z_h are calculated from the expression suggested by Brutsaert (1982).

Comment 2: It is important that the values for z0 and zh used at the Ranchi station are given here, because only then the comparison between model and observations at Ranchi can be interpreted. I guess the value differs from the Ranchi value? This would explain the discrepancies between Cd in Figure 5 from the model and Figure 4 from the offline simulation. The error caused by different values of z0 (equivalent to neutral Cd) can be so large that the stability dependence by using different psi functions is less important. Nevertheless, the comparison with the Ranchi data is not useless because one gets an impression about the structural behavior of model results as a function of stratification compared with measurements. But these points must occur in the Discussion and Conclusion.

Reply: We agree with the reviewer's concern. However, at the moment, due to the inaccessibility of long-term data on detailed surface properties such as vegetation structure needed to quantify the roughness length, we do not have an access to the precise values of z_0 and $\mathrm{z_h}$ at the Ranchi station. Moreover, we wish to highlight that the values of $\mathrm{z_0}$ and $\mathrm{z_h}$ do not directly involve in the estimation of $\mathrm{C_D}$, $\mathrm{C_H}$, and the surface fluxes from the observational data, while they are important in computing these variables using the MOST framework. The error caused by different values of z_0 can be so large that the stability dependence of using different forms of similarity functions is less important in the computation of $\mathrm{C_D}$ and $\mathrm{C_H}$. As a result, three different values of z_0 have been chosen, similar to a recent study by Srivastava and Sharan (2021), which are representative of smooth ($z_0 = 0.01$ m), transition ($z_0 = 0.1$ m), and rough ($z_0 = 1.0$ m) surfaces to account for the impacts of using different $\mathrm{z_0}$ on the estimation of $\mathrm{C_D}$ and $\mathrm{C_H}$ using various functional forms of similarity functions in offline simulations. In addition, the default value of z_0 is used in the revised MM5 surface layer scheme available in the WRF model, which is found to be approximately in the range $0.1 - 0.2$ m at the Ranchi station. Thus, one can interpret the results of $\mathrm{C_D}$ and $\mathrm{C_H}$ shown in Figures 4 and 5 from the offline simulation and the WRF model, respectively.

Figure 4 depicts the offline simulations with equal values of $\mathrm{z_0}$ and $\mathrm{z_h}$. While the revised version of the manuscript also discusses the results from the offline simulations with different values of $\mathrm{z_h}$, assuming $\mathrm{z_0} = 0.1$ m. Figure R1 shows the variation of ζ with $\mathrm{Ri_B}$, $\mathrm{C_D}$, and $\mathrm{C_H}$ with ζ calculated from the bulk flux algorithm using similarity functions corresponding to BD71, CL73, KY90, and F96 with different values of $\mathrm{z_h}$ while $\mathrm{z_0}$ is fixed. The values of $\mathrm{z_h}$ are taken such that the ratio $\ln(\mathrm{z_0}/\mathrm{z_h})$ assumes 0.1, 1, 2, 3, and 4. Figure R1 clearly shows that the estimated values of ζ are similar in near-neutral to moderately unstable conditions for all values of $\mathrm{z_h}$; however, relatively smaller values have been found as the ratio $\ln(\mathrm{z_0}/\mathrm{z_h})$ increases for each form of similarity function. Since the computation of $\mathrm{C_D}$ does not involve the values of $\mathrm{z_h}$ (Eqn. B9), the estimated values of $\mathrm{C_D}$ for each form of similarity function are found to be approximately the same for different values of $\mathrm{z_h}$. However, in the case of $\mathrm{C_H}$, differences are clearly visible if one uses different values of $\mathrm{z_h}$. The estimated $\mathrm{C_H}$ using various similarity functions behaves similarly for different values of $\mathrm{z_h}$, while the magnitude decreases as the ratio $\ln(\mathrm{z_0}/\mathrm{z_h})$ increases.

The text has been added to discuss these issues in the revised version of the manuscript and is presented here for reviewer's reference:

Lines 249-253…Note that, the error caused by different values of z_0 can be so large that the stability dependence of using different forms of similarity functions is less important in the computation of $\mathrm{C_D}$ and $\mathrm{C_H}$. As a result, three different values of z_0 have been chosen, similar to a recent study by Srivastava and Sharan (2021), which are representative of smooth ($z_0 = 0.01$ m), transition ($z_0 = 0.1$ m), and rough ($z_0 = 1.0$ m) surfaces to account for the impacts of using different $\mathrm{z_0}$ on the estimation of $\mathrm{C_D}$ and $\mathrm{C_H}$ from different functional forms of similarity functions in offline simulations.

Lines 254-265…Moreover, Figure 4 depicts the offline simulations with equal values of $\mathrm{z_0}$ and $\mathrm{z_h}$. While in the revised MM5 surface layer scheme available in the WRF model, the values of $\mathrm{z_0}$ and $\mathrm{z_h}$ are not the same. Thus, we have also attempted to discuss the results from the offline simulations with different values of $\mathrm{z_h}$, assuming $\mathrm{z_0} = 0.1$ m. Figure S2 (supplementary material) shows the variation of ζ with $\mathrm{Ri_B}$, $\mathrm{C_D}$, and $\mathrm{C_H}$ with ζ calculated from the bulk flux algorithm using similarity functions corresponding to BD71, CL73, KY90, and F96 with different values of $\mathrm{z_h}$ while $\mathrm{z_0}$ is fixed. The values of $\mathrm{z_h}$ are taken such that the ratio $\ln(\mathrm{z_0}/\mathrm{z_h})$ assumes 0.1, 1, 2, 3, and 4. Figure S2 clearly shows that the estimated values of ζ are similar in near-neutral to moderately unstable conditions for all values of $\mathrm{z_h}$; however, relatively smaller values have been found as the ratio $\ln(\mathrm{z_0}/\mathrm{z_h})$ increases for each form of similarity function. Since the computation of $\mathrm{C_D}$ does not involve the values of $\mathrm{z_h}$ (Eqn. B9), the estimated values of $\mathrm{C_D}$ for each form of similarity function are found to be approximately the same for different values of $\mathrm{z_h}$. However, in the case of $\mathrm{C_H}$, differences are clearly visible if one uses different values of $\mathrm{z_h}$. The estimated $\mathrm{C_H}$ using various similarity functions behaves similarly for different values of $\mathrm{z_h}$, while the magnitude decreases as the ratio $\ln(\mathrm{z_0}/\mathrm{z_h})$ increases.

Lines 283-295…Note that, at the moment, due to the inaccessibility of long-term data on detailed surface properties such as vegetation structure needed to quantify the roughness length, we do not have an access to the precise values of z_0 and $\mathrm{z_h}$ at the Ranchi station. Moreover, the values of $\mathrm{z_0}$ and $\mathrm{z_h}$ do not directly involve in the estimation of $\mathrm{C_D}$, $\mathrm{C_H}$, and the surface fluxes from the observational data, while they are important in computing these variables using the MOST framework. Thus, the default value of z_0 is used in the revised MM5 surface layer scheme available in the WRF model, which is found to be approximately in the range $0.1 - 0.2$ m at the Ranchi station. We wish to highlight that the $\mathrm{z_0}$ used in the WRF model simulations at the Ranchi station is nearly similar to the case of $\mathrm{z_0} = 0.1$ m presented in Figure 4, and the offline simulations also indicate that the behaviour of the estimated $\mathrm{C_D}$ and $\mathrm{C_H}$ with ζ remains almost the same for different values of z_0 with slightly varying magnitudes. Thus, one can interpret the results of $\mathrm{C_D}$ and $\mathrm{C_H}$ shown in Figures 4 and 5 from the offline simulations and the WRF model, respectively, and can compare the WRF model simulated $\mathrm{C_D}$ with the observed one at the Ranchi station. Although the model simulations and observed data may have a different z_0, the comparison of model simulated variables with the Ranchi data allows for an impression of the structural behaviour of model results as a function of stratification compared with measurements.

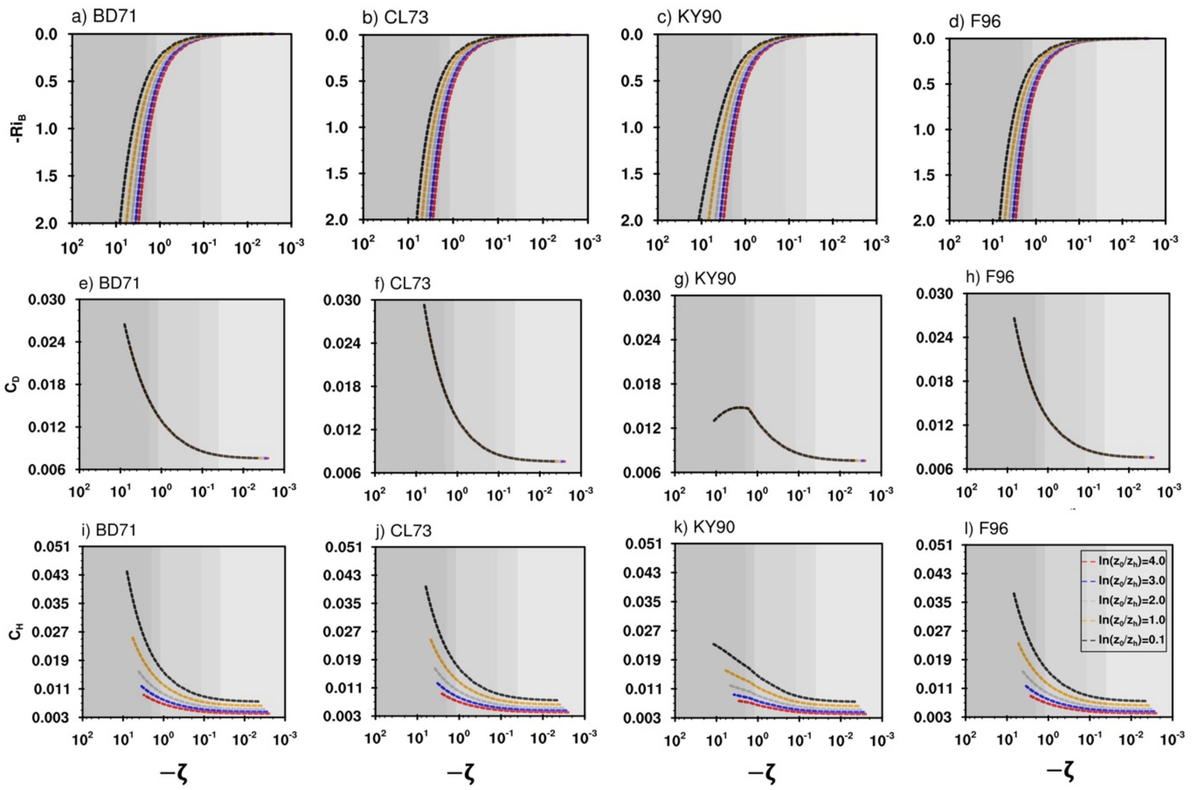

Figure R1: Variation of ζ with Ri_B (upper panel), C_D (middle panel) and C_H (lower panel) with ζ calculated from bulk flux algorithm (offline simulation) for different functional forms of similarity functions corresponding to BD71, CL73, KY90, and F96 forms for different values of z_h for the case when $z_0 = 0.1$ m. The background colour corresponds to different sublayers in convective conditions (Kader and Yaglom 1990), from the dynamic sublayer ($0 \geq \zeta > -0.04$; light grey) to the free convective sublayer ($\zeta < -2$; dark grey).

Comment 3: It is important to know if the reference height for Cd and Ch in Figure 6 is also 10 m, or is the reference perhaps the height of the lowest model grid level? This needs to be said, otherwise the results cannot be interpreted.

Reply: The transfer coefficients C_D and C_H shown in Figure 5 (not Figure 6) are at the reference height corresponding to the lowest model grid level, which is ~12 m in the present study. However, we have also attempted to analyze the variation of C_D and C_H at 10 m. Figure R2 shows the variation of C_D and C_H at 10 m simulated from the WRFv4.2.2 model using different forms of similarity functions corresponding to CTRL and Exp1-3 simulations. It is clear from Figure R2 that the variation of estimated C_D and C_H is almost similar to those presented in Figure 5. We present Figure R2 here solely for the reviewer's reference; it is not included in the manuscript.

A text has been added regarding this in the revised version of the manuscript and is presented here for reviewer’s reference:

Lines 331-333…Note that the transfer coefficients C_D and C_H shown in Figure 5 are at the reference height corresponding to the lowest model grid level, which is ~12 m in the present study. However, we have also analyzed the behaviour of C_D and C_H at 10 m height with ζ and found that they behave similarly to those presented in Figure 5.

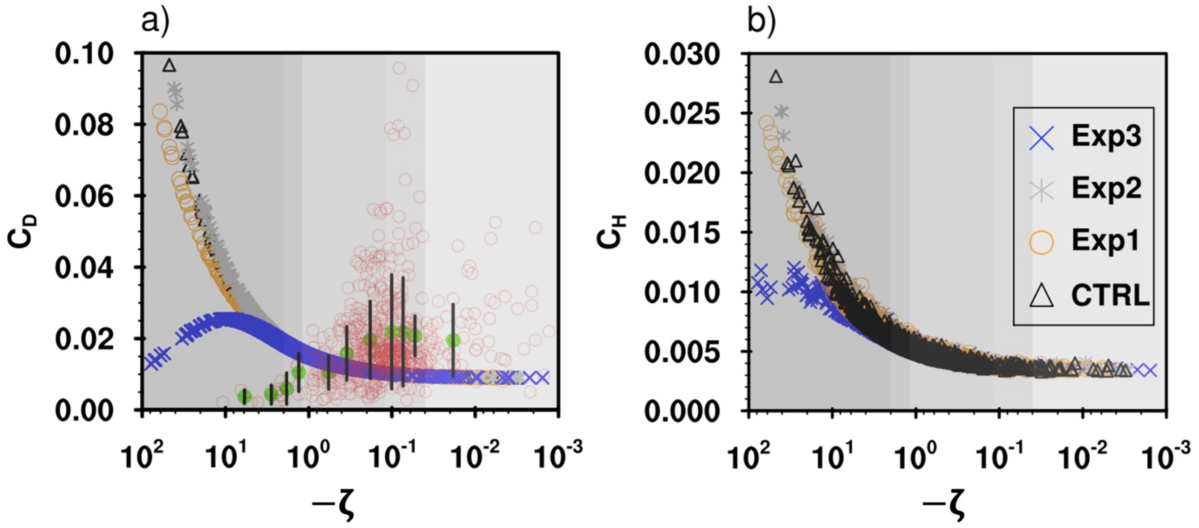

Figure R2: Variation of model simulated (a) C_D and (b) C_H at 10 m height with ζ from different experiments using different similarity functions corresponding to F96 (CTRL), BD71 (Exp1), CL73 (Exp2), and KY90 (Exp3) under convective conditions. The red circles in (a) denote the observed C_D with ζ at the location of flux tower. The mean values of observed C_D in each sublayer are shown with green solid circles along with standard deviations in the form of error bars. Depending upon the data availability, two or three bins of equal width are chosen in each sublayer. The background colour corresponds to different sublayers in convective conditions (Kader and Yaglom 1990), from the dynamic sublayer ($0 \geq \zeta > -0.04$; light grey) to the free convective sublayer ($\zeta < -2$; dark grey).

Minor Revisions

Comment 1: Section 2.1 line 83: to improve the logic I suggest after the sentence ending with Sharan 2021). ....Following MOST they are formulated as ... and then come the equations (1) and (2). Below the sentence explaining the constants, you can add that further details of the Cd and Ch determination are given in Appendix A.

Reply: This has been modified in the revised version of the manuscript and presented here for reviewer's reference:

Lines 81-89…The Monin-Obukhov similarity theory serves as the foundation for the surface layer parameterization (revised MM5 scheme) in the WRF model, and the surface turbulent fluxes are calculated based on the bulk approach using bulk transfer coefficients for momentum (C_D) and heat (C_H) (Namdev et al., 2024; Srivastava et al., 2021; Srivastava and Sharan, 2021). Following MOST, they are formulated as follows:

$$C_D = k^2 \left[\ln\left(\frac{z+z_0}{z_0}\right) - \left\{\psi_m\left(\frac{z+z_0}{L}\right) - \psi_m\left(\frac{z_0}{L}\right)\right\}\right]^{-2} \quad (1)$$

$$C_H = k^2 \left[\ln\left(\frac{z+z_0}{z_0}\right) - \left\{\psi_m\left(\frac{z+z_0}{L}\right) - \psi_m\left(\frac{z_0}{L}\right)\right\}\right]^{-1} \left[\ln\left(\frac{z+z_h}{z_h}\right) - \left\{\psi_h\left(\frac{z+z_h}{L}\right) - \psi_h\left(\frac{z_h}{L}\right)\right\}\right]^{-1} \quad (2)$$

in which k is the von Karmann constant; z_0 and z_h are the roughness lengths for momentum and heat, respectively; ψ_m and ψ_h are the integrated similarity functions for momentum and heat, respectively; and L is the Obukhov length scale.
Their determination based on MOST using integrated forms of the similarity functions is explained in Appendix B.

Comment 2: Line 88: please correct to: ... in which k is the v. Karman constant.

Reply: The needful is done by changing "a" to "the".

Comment 3: Line 109/110: correct to: In this section, we briefly describe the implementation of different similarity functions for unstable stratification in the surface layer parameterization of WRFv4.2.2.

Reply: The needful is done. The modified text is presented here for reviewer's reference:

Lines 108-109…In this section, we briefly describe the implementation of different similarity functions for unstable stratification in the surface layer parameterization of WRFv4.2.2.

Comment 4: Line 110: I suggest writing: Note that two sets of functional forms, namely those suggested by Carl (1973) and the three…

Reply: As suggested by the reviewer the sentence has been modified accordingly as:

Lines 109-111…Note that two sets of functional forms, namely those suggested by Carl et al. (1973) and the three sub-layer model proposed by Kader and Yaglom (1990) for convective conditions have not been included and tested in the surface layer scheme of the WRF modeling framework.

Comment 5: Line 114: add reference for the KANSAS data.

Reply: The following reference for the KANSAS data has been added to the reference list.

Izumi, Y.: Kansas 1968 Field Program Data Report. Bedford, MA, Air Force Cambridge Research Papers, No. 379, 79 pp, 1971.

Comment 6: Line 133: still puzzling: it is still unclear which functions have been newly installed in the WRF model. In section 2.2.1 it is written that Businger (1971) was already used, but here and in Section 2.3 (lines 152, 153) it is stated that BD71, CL73 and KY90 are new. Does BD71 differ from Businger (1971)? This needs clarification.

Reply: In the revised MM5 surface layer scheme, the similarity functions suggested by Businger et al. (1971), Carl et al. (1973), and the three sublayer model by Kader and Yaglom (1990) are newly installed. However, the functions proposed by Fairall et al. (1996) already exist.

In addition, in Section 2.2.1, it is written that the BD71 functions already exist in the older version of the revised MM5 surface layer scheme (i.e., the MM5 scheme; Grell et al., 1994) in the WRF modeling system. However, the BD71 functions are not available in the revised MM5 scheme (Jimenez et al., 2012) considered in this study. In the updated version of the revised MM5 scheme described in this manuscript, the BD71 functions are added.

Comment 7: Line 157: you mean here probably: ....in comparison to the other three functions (BD71,CL73,KY90) whose results are very similar to each other. ?

Reply: The sentence has been modified accordingly as:

Lines 154-156…However, the rate of increase is slightly higher for F96 in comparison to the other three functions (BD71, CL73, and KY90), whose results are very similar to each other (Fig. 2b).

Comment 8: Line 179: correct to: in the surface layer

Reply: The needful is done.

Comment 9: Line 192: it should be: 2x2 km2 and 6x6 km2,

Reply: The needful is done.

Comment 10: Lines 235/236: one can write simply: .... while they differ strongly from values obtained by Exp 3. Throughout the paper: the expression 'it has been observed' is often used, but this formulation is misleading, because 'observation' should be used in connection with measurements. To improve the text, one could write instead: 'it is found' or better, "one can see that" or "Figure .... shows that ......" or "one can see from Figure ... that ....."

Reply: The corresponding text has been modified accordingly in the revised version of the manuscript as:
Lines 228-230…Moreover, results from the BD71, CL73, and F96 functions are even similar at higher instabilities (i.e., the whole range of ζ values), while they differ strongly from values obtained using the KY90 functions (Figure 4a-c).

Moreover, the expression 'it has been observed' has been improved throughout the text as per the reviewer's suggestion.

Comment 11: Line 238: better write: consistent for all ratios z/z0...

Reply: The corresponding sentence has been modified as:

Lines 232-233…This behaviour is found to be consistent for all ratios z/z_0 (Figures 4a-c) representative of smooth, transition, and rough surfaces.

Comment 12: Line 242: Please check figure names in this paragraph, e.g. Figures 4b1, 4b2 do not exist.

Reply: This is clarified in the text. Now the subplots in Figure 4 are referred to as 4a-i in the diagram as well as in the text.

Comment 13: Lines 259/260: This is a repetition. If you want to summarize here, one can write To summarize, ...

Reply: The corresponding text has been removed from the revised version of the manuscript.

Comment 14: line 262: It is a pity. One could have added a figure showing this comparison using the observed roughness length.

Reply: It is not feasible at the moment due to the inaccessibility of long-term data on detailed surface properties such as vegetation structure needed to quantify the roughness length. We do not have an access to the precise values of z_0 and z_h at the Ranchi station.
The corresponding sentence has been removed in the revised version of the manuscript.

Comment 15: Line 266: the flux tower

Reply: The needful is done by replacing "a" by "the".

Comment 16: Line 275: To make it clearer (see also my major revision) I suggest writing: Although the absolute values of the parameters differ from each other due to the different prescribed roughnesses the variation with Rib .... Is very similar as in the offline results .....

Reply: The needful is done by modifying the corresponding text accordingly as:

Lines 281-282…Although the absolute values of the parameters differ from each other due to the different prescribed roughnesses, the variation of ζ with Ri_B, C_D and C_H with ζ is very similar to the offline results.

Comment 17: Line 310-312: Considering Figure 5, it seems that this statement is not correct because in the neutral case (Rib going to zero) neutral values of Cd and Ch differ strongly from each other. I also do not think now that the different surface temperatures can explain the scatter in the modelled Ch. Please consider equations B8, B9, B10. For given zeta, z, z0 and zh there is only one value of Ch. There is no additional dependence on the surface temperature. Another reason must exist for the scatter and as I wrote in my first review, I still think that it might be due to the determination of zh in WRF, or there is a numerical reason (?)

Reply: We thank the reviewer for this omission in the revised MM5 surface layer scheme available in the WRF modeling system, which uses different values of z_0 and z_h. Moreover, we agree with the reviewer that the relatively large scatter in the values of C_H simulated by the WRF model can be attributed to the determination of z_h.

The text related to this has been modified in the revised version of the manuscript and is presented here for reviewer's reference:

Lines 329-330…The relatively large scatter in the values of C_H simulated from the WRF model can be due to the parameterization of the ratio of momentum and scalar roughness lengths in the model.

Comment 18: Line 360: correct to over the whole

Reply: The needful is done.

References:

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9. Namdev, P., Srivastava, P., Sharan, M., & Mishra, S. K.: An Update to WRF Surface Layer Parameterization over an Indian Region, Dynam. Atmos. Ocean, 105, 101414, https://doi.org/10.1016/j.dynatmoce.2023.101414, 2024.
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12. Srivastava, P., and Sharan, M.: Uncertainty in the Parameterization of Surface Fluxes under Unstable Conditions, J. Atmos. Sci., 78, 2237–2247, https://doi.org/10.1175/JAS-D-20-0350.1, 2021.