***Topical Editor Initial Decision: Publish subject to minor revisions (Editor review)** (11 Feb 2014) by Hella Garny*
Comments to the Author:
Dear Prof. Gao,

thank you for the revision of your manuscript and the author's response. All comments were answered sufficiently and following the overall positive response of the reviewers I think there will be no problem in accepting this paper for GMD.

However, unfortunately there was a mix-up in the date of the end of the discussion phase for the manuscript, so that one reviewer had no chance to post his/her comments. Instead, the review is provided below. While your paper is in a good condition already, I think it would be great if you used the additional comments for potential additional benefits to your publication. Sorry for the troubles and unusual process.

Dear Dr. Hella Garny,

Thank you very much for your evaluation. The comments from the third reviewer has helped us improve the manuscript a lot. The detailed response is as follows. Red color indicates the modification in the first revision round, and blue color indicates the modification in the current round.

Response to comments by Anonymous Referee #3

The paper presents a new methodology to approximate iterative solutions for surface-layer transfer coefficients of momentum and heat with an improved non-iterative solution. The new proposed methodology proves much better accuracy than any previous non-iterative approximation (in particular the recently published wouters et al., 2012). In general, the results are clearly described. I would recommend to publish this paper after dealing with the comments below.

We thank the reviewer for his/her thorough assessment and constructive suggestions.

My main concern is that I'm not entirely convinced of the added value of the new non-iterative approximation (that needs 9 pages of parameter values) over the previous approximation WRL2012, and over the iteration with 5 steps. This is also the concern *of the anonymous reviewer #1, and needs to be addressed in the paper.*

In particular, the errors and uncertainty arising from any parameterization or parameter value in the iterative solution can be substancial compared to the errors made by the approximations WRL2012 or the iteration with 5 steps, and needs to be discussed. These parameters include for instance the parameters in the stability function psi_m psi_h (a, b, c, d) , or z_0/z, kB-1, z/z_0. In order the address this, I recommend to put the comparison of the accuracy of the different non-iterative approximations with the iterative approximations in perspective to the impact of uncertainty in the parameter values of the stability functions psi_m and psi_h (or any other parameterization used in the formulations like z_0/z*). Cheng and brutsaert 2005 pointed out that there is some scatter in the observations and thus uncertainty on the stability functions. In particular, when replacing the psi_h-function with the psi_m-function, CB05 only has a minor impact on the error of the stability functions because of uncertainty and natural variability of the observations. Furthermore, the stability functions may include additional errors/uncertainty for urban areas as well (with low z0h). Therefore, it needs to be verified whether the CASES-99 observations used in the Cheng and Brutsaert methodology also includes urban sites. My suggestion is to analyze the propagation of these errors/uncertainties (for instance by effectively replacing psi_h with psi_m) to the iterative transfer coefficients and compare this with the errors made in the non-iterative approximations or iterative solutions with limited iteration steps. This way, one is able to address the added value of having higher accuracy of the non-iterative approximations (that needs large complexity in the formulations), or to address the consequences of using non-iterative solutions with lower accuracy or iterative solutions with limited iteration steps. In this respect, it also needs to be addressed in later studies what would be the overall impact of either employing an iterative appproximation (either with or without limited iteration step) or else a non-iterative approximation on performance and speed of SVAT-models or atmospheric models, taking urban areas in to account.*

You could add a brief discussion of the pros and cons of using any of the iterative (including the one with limited iteration steps) methodologies or non-iterative approximations, for instance by including a small table. This discussion should concern the simplicity in the implementation, computational cost and accuracy. Even though it is not the focus of this paper, maybe you could add some recommendations for the unstable region as well?

Response: Although there are 9 pages of parameters, and this may add some workload in coding the equations, the new scheme is accurate and efficient. We have added more discussion in the paper:

"The calculation error of $\zeta = f\left(Ri_{\mathrm{B}}, L_{0\mathrm{M}}, kB^{-1}\right)$ is always controlled to be within 5% (when $\zeta \le 0.5$) and 10% (when $\zeta > 0.5$). The calculation procedure is also simple, for a small Ri_{B} (i.e., $Ri_{\mathrm{B}} < Ri_{\mathrm{Bc1}}$), only one time computation of Eq. (23) and (24) will suffice. The maximum computation step is 6 times of Eq. (24) and one time of Eq. (23) when it is in region 1 or 7 and at the same time Ri_{B} is large (i.e., $Ri_{\mathrm{B}} > Ri_{\mathrm{Bc6}}$). Note that the Eq. (24) has only a maximum of 8 elements and a minimum of 4 elements so the calculation is still efficient. The new equations involve a large number of parameters which increase the complexity of coding. However, the effort of coding the new scheme is minimal as compared to its potential gain, which includes the accuracy of the new scheme and the avoidance of iterations. Besides, a compromise can be made between accuracy and complexity. For models that are not interested in high kB^{-1} values, region 1 and 2 (i.e., $10 \le z / z_0 \le 10^5$ and $-0.607 \le z_0 / z_{0\mathrm{h}} \le 100$) have provided reasonable coverage (see Garratt, 1992; Launiainen, 1995), and the other 6 regions can be ignored. For example, in WRF model MM5 surface module, $z_{0\mathrm{h}} = z_0$ is assumed during the calculation of frictional velocity (Jiménez et al, 2012). While for models that include urban surface effects, it is better to keep all the regions. Further, CB05 probably is not the final solution for the surface flux calculation under stable stratification. The method used to derive non-iterative equations presented here can be used in future studies to transfer the new iterative algorithm to non-iterative equations."

Yes, not only there are some uncertainty in CB05 equations, but also the applicability of MOST theory in very stable region is in doubt. However, the purpose of this paper is not to improve the accuracy of CB05 or MOST theory, but the efficiency of CB05, i.e., propose a method to transform iterative equations of CB05 to non-iterative equations (which is the exact same purpose as WRL12), and the method in this paper can be used in future to transform new and more accurate iterative equations to non-iterative. Therefore, verifying the uncertainty in parameters of iterative equations (i.e., CB05) is beyond the scope of this paper. However, we will carry out the verification with observation data in our following studies. The unstable region will also be verified and then an optimal choice of the scheme for unstable region will be recommended.

In the introduction part, we have added more discussion about the uncertainty of iterative methods based on MOST.

“With data collected in the field program CASES-99 (Cooperative Atmosphere-Surface Exchange Study-99) (Poulos et al., 2002), Cheng and Brutsaert (2005, CB05 hereinafter) further provided a new scheme and it is confirmed to perform better by later research (Guo and Zhang, 2007; Jiménez et al, 2012). Based on the measurements made during experiment SHEBA in Arctic and Halley 2003 experiment in Antarctica, Grachev et al. (2007) and Sanz Rodrigo and Anderson (2013) proposed different similarity functions, respectively. Through systematic mathematical analysis, Sharan and Kumar (2011) proved that similarity functions of CB05 and Grachev et al. (2007) were applicable in the whole stable stratification region. However, all of these studies are based on MOST and application of MOST in very stable condition is in doubt since it assumes that turbulence is continuous and stationary, while in very stable condition turbulence is weak, sporadic and patchy (Sharan and Kumar, 2011). Grachev et al. (2013) indicates that the applicability of local MOST in stable conditions is limited by the inequalities, when both gradient and flux Richardson numbers are below their "critical values" about 0.20-0.25. Further, MOST predicts that mean gradients of turbulence become independent of z in very stable condition, Wyngaard and Coté (1972) first referred to this limit as ‘z-less stratification’. BD equations follow this prediction, but CB05 and Grachev et al. (2007) do not. To avoid these holdbacks and self-correlation of MOST, Sorbjan (2010) and Sorbjan and Grachev (2010) discussed an alternative local scaling for the stable boundary layer (referred to as gradient-based scaling) when different universal functions plotted versus the gradient Richardson number instead of the Monin-Obukhov stability parameter.”

In current numerical models, CB05 is widely used for stable region, however, mainly with only 5 steps iteration, so the calculation results are not the exact solution of CB05 (see Fig. 4 of the paper). Indeed, CB05 has its own uncertainty compared with observation, but one cannot say that we don’t need the accurate solution of CB05 because it is already biased. Since CB05 is the prevailing optimal method, we have to derive the accurate solution of CB05 and try to avoid adding more error in the calculation procedure (while WRL12 and CB05 with 5 steps iteration will, see Fig. 4 and Fig. 6). A table has been added to the paper to show the characteristics of the 4 methods (CB05 with ultimate iteration, CB05 with 5 steps iteration, WRL12 and the new equations). With this table, it is easy to see the advantage of the new equations.

Table 11. Summarization of the characteristics of the four methods. Calculation time is the time each method needs for computing ζ from Ri_B, z_0 and z_{0h} in the range $0 < Ri_B \le 2.5$, $10 \le z/z_0 \le 10^5$ and $-0.5 \le \log(z_0/z_{0h}) \le 30$ with the interval of

0.01 for Ri_B, 0.035 for $\log(z/z_0)$ and 0.1 for $\log(z_0/z_{0h})$. The calculation is performed on a desktop computer with an Intel Core i5 processor, and note that the calculation time can vary with different computer.

Method	Calculation time	Maximum $\Delta\zeta$	Average $\Delta\zeta$	Characteristics and suggestion
CB05 with ultimate iteration	6260 s	N/A	N/A	Current optimal method, but with high computational cost. Use this method when computing power is not an issue.
CB05 with 5 steps iteration	3960 s	exceeds 50%	exceeds 15%	Lower computational cost, but add more uncertainty in the calculation procedure of CB05.
WRL12	261 s	exceeds 50%	exceeds 15%	Much lower computational cost, but add more uncertainty in the calculation procedure of CB05.
New equations	549 s	smaller than 5% (when $\zeta \leq 0.5$) and 10% (when $\zeta > 0.5$)	smaller than 2%	Low computational cost, error in the calculation procedure of CB05 is controlled within 10%. Use this method to have an optimal compromise between accuracy and computational cost.

MINOR comments:

throughout the text (e.g. r15 6460): the earth's surface'

Response: Revised

6460 r. 21 B-D -> BD instead of B-D (seems to be the abbreviation used later on?)

Response: Revised

6461 r.1 AND r.7: Jiménez et al. 2012.... also in the remainder of the text

Response: Revised

6462 r. 16 'or neglecting/accounting for the roughness sublayer effects.'

Response: Revised to ‘accounting’.

6469 r.12: it seems to be suggested that the accuracy by employing the original methodology of WRL12 can be improved? However, this needs to be verified. But maybe you mean that the accuracy of WRL2012 'needs' to be improved by means of a new methodology (so the one presented by the current paper)? But in that case, the 'need' has to be investigated by the paper (see also first major comment).

Response: Sentence changed to ‘WRL12 proposed a way to avoid the iteration, but it introduces large error in the calculation procedure so that its calculation accuracy needs be improved.’

6469: r.24: 'weather forecasting models' or 'weather prediction models'

Response: Revised to ‘weather forecasting models’.

please reformulate 6465 r.18. For example:
In order to reduce the complexity, weakly and strongly stable conditions are treated seperately in previous studies (e.g., Launiainen, 1991; Li et al., 2010; WRL12). Analogously, multiple regions are considered for z0 and z 0h for the regression of ζ = f(RiB , L0M , kB-1) in this paper.

Response: Revised to ‘In order to reduce the complexity, weakly and strongly stable conditions are treated separately in previous studies (e.g., Launiainen, 1995; Li et al., 2010; WRL12). Analogously, multiple regions are considered for z_0 and $z_{0\mathrm{h}}$ for the regression of $\zeta=f\left(Ri_{\mathrm{B}}, L_{0\mathrm{M}}, kB^{-1}\right)$ in this paper’.

pp. 6468
r.1 : leave away 'here'

Response: Revised

r.5 : where (lowercase)

Response: Revised

r.15: Here, AverageError(zeta) ...

Response: We do mean ‘Error(zeta)’ at the rhs of the equation. Sentence changed to ‘Here $Error(\zeta)$ indicates $\Delta\zeta$ or $\Delta C_{M,H}$ at a particular ζ , z_0 and z_{0h} .’

please reformulate r. 18, e.g.: 'The results indicate that the maximum delta zeta exceeds... when using CB05 with 5 iteration steps or WRL12, whereas the averaged delta zeta exceeds 15%. On the contrary, the maximum delta zeta ...."

Response: suggestion followed, sentence revised.

please recheck (consistency of) references:
e.g.
pp.6465 r. 19: lauriainen 1991 -> launiainen 1995 ??

Response: checked and revised.