Evaluation of Different Methods to Model Near-Surface Turbulent Fluxes for an Alpine Glacier in the Cariboo Mountains, BC, Canada

August 7, 2017

Dear Editor,

I reviewed the paper "Evaluation of Different Methods to Model Near-Surface Turbulent Fluxes for an Alpine Glacier in the Cariboo Mountains, BC, Canada" Ice by Radic and others.

The paper discusses the often neglected topic of the accuracy of turbulent fluxes in mountain environments. The calculations of turbulent fluxes are addressed using data as well as a range of relevant parameterisations and the results are well worth publishing. I look forward to seeing this important work published.

Generally the paper is well written, but I did find it cumbersome to read, because it includes many different parameterisations that are not easily distinguishable in the text. So I suggest that the authors consider a restructuring of the methods to clarify the difference between the model runs they performed and maybe "cluster" the methods that are similar.

I discuss my other suggestions to the authors in the comments below.

Sincerely,
Ruzica Dadic

General comments

- My main concern with the paper is that it neglects the very stable conditions by only looking at conditions where wind speed is ¿3m/s or (the moisture/temperature gradients are large enough). I appreciate that the measurement of turbulent fluxes under very stable conditions are harder to obtain because the mean flow is non-stationary and characterised by brief episodes of intermittent turbulence Mahrt [1989]; Beljaars and Holtslag [1991]; Mahrt [1998]; Cheng et al. [2005] . Considering the significant amount of the periods where low wind speeds occur (Figure 4 in the submitted manuscript), those periods should not be neglected when trying to improve the turbulent fluxes parameterisations over glaciers. A number of studies have been dedicated to finding valid flux-profile relationships for very stable conditions, such as are often found over snow and ice surfaces [e.g. Webb, 1970; Kondo et al., 1978; Lettau, 1979; Brutsaert, 1982; Holtslag and de Bruin, 1988; Beljaars and Holtslag, 1991; Cheng and Brutsaert, 2005; Grachev et al., 2007] and those studies have also been applied to snow and ice surfaces [Pomeroy et al., 1998; Jordan et al., 1999; Sharan, 2009; Dadic et al., 2011].

- All bulk methods assume a logarithmic profile, and they only differ in what stability correction they use. This should be clarified in the manuscript.

- Figures 1, 2, and some of Figure 4 (radiation, precipitation, wind direction) are not needed in this paper and can be removed.

- Figure 5: It is of no surprise that pretty much all 4 methods in this Figure have the same results, considering they all use he bulk method at almost neutral conditions. By neglecting the stable conditions, they don't have much reason not to vary. I am therefore not sure what the point of his comparison is.

- P18–19: It is not surprising that the "parameterisations" which use measured u_* as input lead to an increase in fit with the data. u_* goes into the Q_E equation by the power of 4, it's proportional to Q_H. It changes L with the power of 3, so will disproportionally decrease z/L. Some of this discussion (why u_* has more influence on the turbulent fluxes calculation than z/L) might be easier to understand by just looking at the equations and the relevance of the different parameters.

  Furthermore, I the observation on page 18 (L1–3) that the C_{log} and C_SR methods are not justified in table 3, where the difference between the u_* models in the correlation coefficient r is between 0.94 and 0.95 for Q_E and between 0.82 and 0.85 for Q_H, which is not exactly significant. I am not sure how to address this problem, but I'm sure the authors can come up with more robust conclusions than that.

- p 29, L1-2: Considering that the authors have most SEB components to actually calculate the surface temperature, and that the surface temperature is an important feedback for the TF, the authors should consider calculating the surface temperature and including it in their calculations using the different paramaeerizations. It would be interesting what effect the different parameterizations have on surface temperature. I do not expect the authors to change all their results now, but maybe it's worth a discussion in the paper.

- p 30, L26-30: Considering that only near-neutral conditions are used for this study, I am not surprised that the stability corrections show very little difference when modelling the fluxes.

- P31, L11-13: As far as I remember, the reason why the turbulent fluxes are suppressed in Conway and Cullen (2013) is that they assumed the log-linear relationship to be valid under very stable conditions. The log-linear relations, however, do not allow for significant fluxes to occur at very strong stability[Monin and Yaglom, 1971; Mahrt, 1998; Pleim, 2006] and underestimate the turbulent fluxes over these conditions [e.g. Deardorff, 1968; Webb, 1970; Kondo et al., 1978; Louis, 1979; Hogstrom, 1988; Launiainen, 1995; Mahrt, 1998; Jordan et al., 1999; Stössel et al., 2010].

  The Figure below is unpublished, but it shows how the log-linear profile behaves under very stable conditions ($\zeta > 1$ or low wind speeds) for different climatic conditions.

References

Beljaars, A. and Holtslag, A. (1991). Flux parameterization over land surfaecs for atmospheric models. *Journal of Applied Meteorology*, 30:327–341.

Brutsaert, W. (1982). *Evaporation into the Atmosphere: theory, history and applications.* D. Reidel Publishing Co.

Cheng, Y. and Brutsaert, W. (2005). Flux-profile relationships for wind speed and temperature in the stable atmospheric boundary layer. *Boundary–Layer Meteorology*, 114:519–538.

Cheng, Y., Parlange, M., and Brutsaert, W. (2005). Pathology of Monin-Obukhov similarity in the stable boundary layer. *Journal of Geophysical Research*, 110(D6).

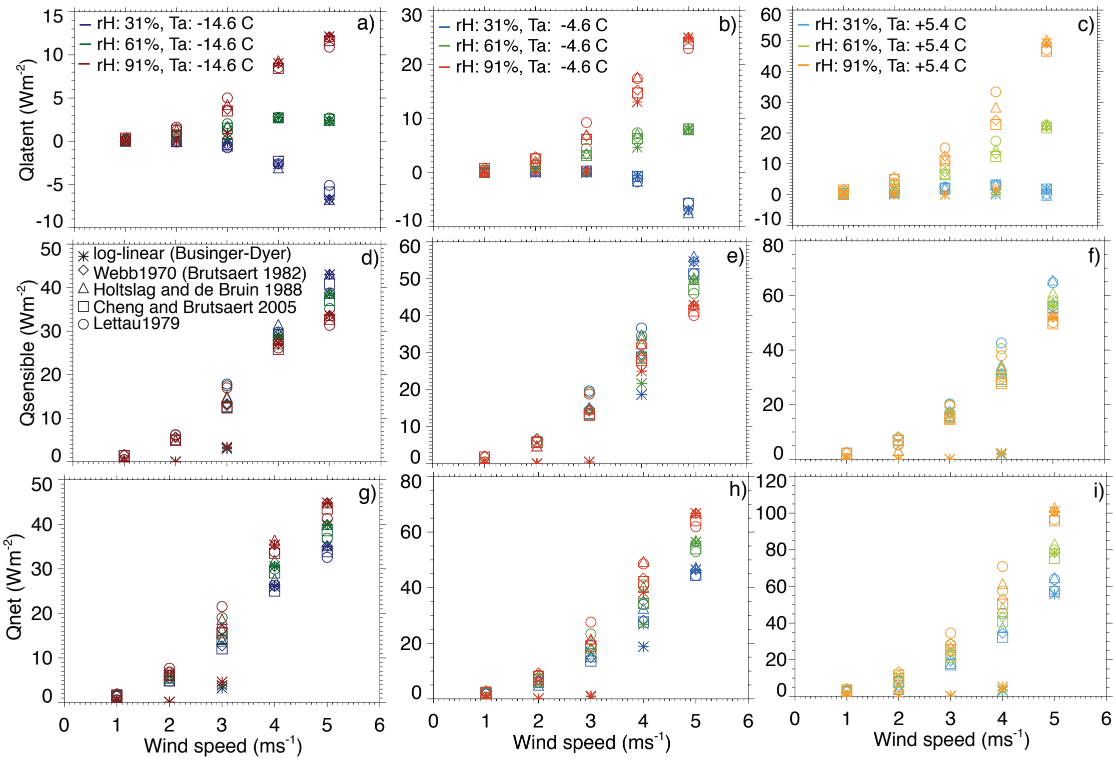

Figure 1: Turbulent fluxes as function of wind speed (1–5 ms^{-1}) for 9 different climatic conditions calculated with 5 different flux-profile relationships for the stability correction. The Basinger-Dyer parameterisations is purely log-linear and surpasses turbulent fluxes when $\zeta > 1$.

Dadic, R., Mott, R., Lehning, M., Carenzo, M., Anderson, B., and Mackintosh, A. (2011). Sensitivity of turbulent fluxes to wind speed over snow surfaces in different climatic settings. *Advances in Water Ressources*, submitted.

Deardorff, J. (1968). Dependence of air-sea transfer coeffinients on bulk stability. *Journal of Geophysical Research*, 73(8):2549–2557.

Grachev, A., Andreas, E., Fairall, C., Guest, P., and Persson, P. (2007). SHEBA flux-profile relationships in the stable atmospheric boundary layer. *Boundary–Layer Meteorology*, 124:315–333.

Hogstrom, U. (1988). Non-dimensional wind and temperature profiles in the atmospheric surface layer: a re-evaluation. *Boundary–Layer Meteorology*, 42:55–78.

Holtslag, A. and de Bruin, H. (1988). Applied modeling of the nighttime surface energy balance over land. *Journal of Applied Meteorology*, 27:689–704.

Jordan, R., Andreas, E., and Makshtas, A. (1999). Heat budget of snow covered sea ice at north pole 4. *Journal of Geophysical Research*, 104(C4):7785–7806.

Kondo, J., Kanechika, O., and Yasuda, N. (1978). Heat and momentum transfers under strong stability in th eatmospheric surface layer. *Journal of the Atmospheric Sciences*, 35:1012–1021.

Launiainen, J. (1995). Derivation of the relationship between the obukhov stability oarameter and the bulk richardson number for flux-profile studies. *Boundary–Layer Meteorology*, 76:165–179.

Lettau, H. (1979). Wind and temperature profile prediction for diabatic surface layers including strong inversion cases. *Boundary–Layer Meteorology*, 17:443–464.

Louis, J.-F. (1979). A parametric model of vertical eddy fluxes in the atmosphere. *Boundary–Layer Meteorology*, 17:187–202.

Mahrt, L. (1989). Intermittency of the atmospheric boundary layer. *J. Atmos. Sci.*, 46:79–95.

Mahrt, L. (1998). Stratified atmospheric boundary layers and breakdown of models. *Theoret. Comput. Fluid Dynamics*, 11:263–279.

Monin, A. and Yaglom, A. (1971). *Statistical Fluid Mechanics: mechanics of turbulence, Vol. 1.* Number 769 pp. MIT Press, Cambridge, Massachusetts.

Pleim, J. (2006). A simple, efficient solution of flux-profile relationships in the atmospheric surface layer. *Journal of Applied Meteorology and Climatology*, 45:341–347.

Pomeroy, J. W., Gray, D. M., Shook, K. R., Toth, B., Essery, R. L. H., Pietroniro, A., and Hedstrom, N. (1998). An evaluation of snow accumulation and ablation processes for land surface modelling. *Hydrological Processes*, 12:2339–2367.

Sharan, M. (2009). performance of various similarity functions for nondimensional wind and temperature profiles in the surface layer in stable conditions. *Atmospheric Research*, 94:246–253.

Stössel, F., Guala, M., Fierz, C., Manes, C., and Lehning, M. (2010). Micrometeorological and morphological observations of surface hoar dynamics on a mountain snow cover. *Water Resources Reasearch*, 46(W04511).

Webb, E. (1970). Profile relationships: The log-linear range, and extension to strong stability. *Quarterly Journal of the Royal Meteorological Society*, 96:67–90.