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Interactive comment on "Contrasting radiation and soil heat fluxes in Arctic shrub and wet sedge tundra" *by* I. Juszak et al.

I. Juszak et al.

inge.juszak@gmx.de

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We thank Mr Launiainen for the positive evaluation of our manuscript and for his comments and suggestions. We are also grateful for his advice on how our work can be relevant to the modelling community.

GENERAL COMMENTS

1. To gain further understanding, the experimental results need to be considered together / analyzed with soil-vegetation-atmosphere transfer models. Inclusion of relatively simple model schemes (e.g. canopy radiative transfer, soil heat balance) would allow explaining the empirical findings using theoretical grounds. I understand this may be unrealistic for the current study, and thus encourage the

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authors to publish the dataset to allow its use by the modeling community.

Using a model would be interesting, but would extend well beyond the scope of our paper. We will hence provided all available meteorological driving variables (radiation fluxes and air temperature) in combination with our canopy and soil data via Pangea to allow for such modelling in follow-up studies.

2. From modeling perspective, it is unfortunate that e.g. soil surface temperature, wind speed, and turbulent heat fluxes from the combined shrub/sedge ecosystem were not measured at the study site?

   Ecosystem-scale measurements were done nearby our study location at a flux tower operated by the VU Amsterdam (van der Molen et al., 2007; Parmentier et al., 2011; Budishchev et al., 2014). However, the measurements do not include soil surface temperature. The data are accessible via the European flux database (Russia, Chokurdakh, http://www.europe-fluxdata.eu). Unfortunately, the small size of the vegetation patches and the permafrost conditions did not allow vegetation type specific measurements of sensible and latent heat flux. Such measurements would have been useful for understanding the energy budget of the different vegetation types.

SPECIFIC COMMENTS

P7 L9–11 Please clarify: In order to reduce the solar angle influence, we took daily average fluxes of K and L to compute Rn, alpha and T for the analysis of vegetation type and cloud cover effect. Later, you show how you calculate e.g. cloud cover for each 10min period, and show In the solar angle dependency of above parameters separately for clear-sky and cloudy conditions (Figs. 5, 7 & 8) so is there a mistake in text?

The solar angle influence was reduced to estimate the mean vegetation and cloud effects as shown in Table 1 (and in the text). On the other hand, we analysed the effect of solar angles on the radiation budget as shown in the Figures 5, 7 & 8. We will change the paragraph to better distinguish between the two methods.

As Reviewer 1, I would expect to see e.g. ensemble diurnal cycles of Rn/Kdn, Lnet, alpha and T. Such a figure could replace Fig. 8 which I consider unnecessary since same information is given already in Fig. 7.

We will remove the former Figure 8 and add a new figure (see Figure 1 below) with the diel cycles.

P8 L 15–25 Please clarify: What are the total LAI's & WAI (woody area index) above sub-canopy radiation sensors for shrub and sedge-sites. These are needed to interpret canopy transmittance (T). Does the LAI of sedge (1.4 +/- 0.3 m2m-2) include the dead standing leaves? If not, what is their LAI?

For dwarf shrubs, LAI and WAI would ideally have been completely above the sub-canopy sensor. There is a little difference between the two sensor types used for below canopy radiation. The sensor for time series measurements of shortwave transmittance was 34 mm high, roughly 13% of the canopy height of dwarf shrubs. Thus we assume that about 80% of the LAI and WAI are above this sensor. The PAR sensor (Figure 8c, former Figure 7c) is only 16 mm thick and thus should measure the transmittance of almost the complete canopy. The sedge LAI as measured in the field includes only the green leaves. We included this clarification in multiple places in the text now. We also estimated the standing dead sedge leaf area index and found that it was about 1.1 times green leaf area. We found a mistake in the original computation and will update this value to the correct number. However, we cannot include the dead leaves in the area estimate in Figure 3 as it was not measured on the same eight plots as the green leaf area index. Instead, the ratio between green and dead leaves was estimated on three additional plots destructively.

P10 L 18-19 The differences in transmittance (clear-sky vs. cloudy) can be explained by different plant-area index (LAI+WAI) of shrubs and sedges, and partly by different leaf orientation (spherical vs. vertical leaf angle distribution).

We agree and will add this to the discussion section.

P11 Fig 5 Maybe consider showing Rn relative to incoming global radiation (Kdn)? Now you compare apples and oranges since global radiation varies strongly between cloudy and clear-sky conditions, and with solar zenith angle.

Figure 5 was not meant for a comparison between albedo and net radiation but rather to show both quantities independently. Figure 2 below shows the net radiation normalised with incoming shortwave radiation in comparison with the original figure panels. Normalised net radiation decreases with higher solar zenith angles in the same way for both vegetation types.

We would prefer to keep the original Figure 5 instead of replacing the panels a and b with the panels c and d of Figure 2 below as net radiation is commonly used and easier to interpret than normalised net radiation.

P12 L5 Would be interesting to see ensemble diurnal cycles of soil heat flux, soil-air temperature gradient and radiation (net short- and longwave) for core growing season. See also later comment.

We will add the requested figure (see Figure 1 below).

P14 L9 and P15 L30–31 Plant-area index (PAI) is the main control of light extinction within canopies, not canopy height. Of course, taller canopies have often high PAI, and also more complex architecture (at shoot, branch, canopy levels) that enhance absorption of solar radiation compared to shallow vegetation. This is a section where use of a simple canopy radiation models (e.g. Spitters, 1986; Zhao and Qualls, 2005) would have been beneficial to back up the discussion.

We agree that canopy absorptance and transmittance strongly depend on PAI while canopy architecture (height and angle distribution) is a secondary control.

We will clarify the sentence in question. Furthermore, we agree that models of canopy radiation transfer can be a valuable tool for understanding the differences between the radiation budget of the two vegetation types. However, we covered radiative transfer modelling of different tundra vegetation types in a second manuscript which is currently under review in *Remote Sensing of Environment*. Hence, it should not be repeated here. Since that paper is not yet formally accepted we did not cite it, but as soon as it becomes citable we will do so. Our modelling results agree well with the field observations. While wet sedge albedo is 0.03 higher than dwarf shrub albedo, sedges transmit 7% less shortwave radiation.

P17 L3–18 This is a section where use of soil heat transfer models could be of great help. You arrive into conclusion that net radiation at the soil surface is not a major cause of shrub/sedge plot difference in soil heat flux. So, one could use same upper forcing for both plots (shrub/sedge) and ask how much the different soil properties (thermal conductivity, heat capacity that are measured) explain the observed difference in soil heat flux at 10 cm depth. Deeper non-saturated layer and 5 cm thick moss cover at shrub site are likely to act as an insulating media. This restricts heat conduction to deeper layers reducing the heat flux measured at 10cm depth. As consequence, the diurnal variability of top soil temperature (measured at 4cm depth?) and top soil heat storage change at shrub site should be much greater than at the sedge site. If this is not the case, then it is the soil surface energy budget that explains the difference. Since you think net radiation is not significantly different, this would mean that net turbulent energy transfer (sensible + latent heat) should be stronger at the shrub site. Because shrub canopy is sparser than sedge canopy, I would expect that eddy diffusivity (exchange coefficient) is larger for shrub. Without detailed model it is not easy to speculate what happens to latent heat flux from moss-dominates soil surface (shrub-site) vs. moist peat/litter surface at the sedge sites. The analysis of soil –

air temperature difference and its seasonal / diurnal variability should, however, give some indication of possible differences in the sensible heat exchange. See e.g. Stoy et al. (2012) if interested on possibly significant impacts of moss cover /moss type on soil heat flux and temperature, and Launiainen et al. (2015) for an example of modeling soil-moss-air energy exchange below plant canopies.

We agree that modelling of the active layer temperature and heat flux may help understanding the interactions between vegetation, radiation, and soil heat flux. As mentioned above, we will make all necessary data available on Pangaea for in-depth modelling studies. In the text, we will add the moss component and the very helpful considerations made by this reviewer to the discussion, including the named citations.

TECHNICAL CORRECTIONS

P2 L15 Vegetation alters the radiation budget and turbulent energy fluxes at the soil surface... and turbulent energy fluxes will be added

P4 L7 volumetric soil moisture volumetric will be added

P4 L8 – P5 L4 Please note here that you measured the thermal conductivities and heat capacities at the sites. will be added

P5 L5 At first read I was expecting energy fluxes to include also sensible and latent heat. Please be more exact in the 1st sentence of the chapter; you measured only radiation above and below the canopy, and soil heat flux at 10cm depth. Will be changed

P13 L9 Include definition of active layer depth for a general reader? General definition will be included in Section 2.1

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P16 L22 Spatial variability of transmissivity is thus related to spatial inhomogeneity of canopy structure. Will be added

P16 L31 drivers of processes but causes of differences Will be changed

P17 L2 ... and activity, and by soil processes (not or) Will be changed

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Figure 1 (a) Average diel cycle of above canopy shortwave (K) and longwave (L) radiation fluxes, (b) above canopy net shortwave (K_n), net longwave (L_n) and net (R_n) radiation, (c) albedo (α) and transmittance (T), (d) soil temperature (T_s) at 4 cm depth and soil heat flux (HF) at 10 cm depth, and (e) air temperature at 1.7 m above the soil surface (T_a) and gradient between air and soil temperature (ΔT) of dwarf shrubs and wet sedges during the growing season; solar noon at 14:00 local time.

Figure 2 Dependence of (a,b) net radiation and (c,d) net radiation divided by incoming shortwave radiation on solar zenith angle and cloud cover for (a, c) dwarf shrub and (b, d) wet sedge, growing season mean $\pm$ standard deviation values calculated for 2° intervals; the dashed lines represent the mean diel value under each condition.

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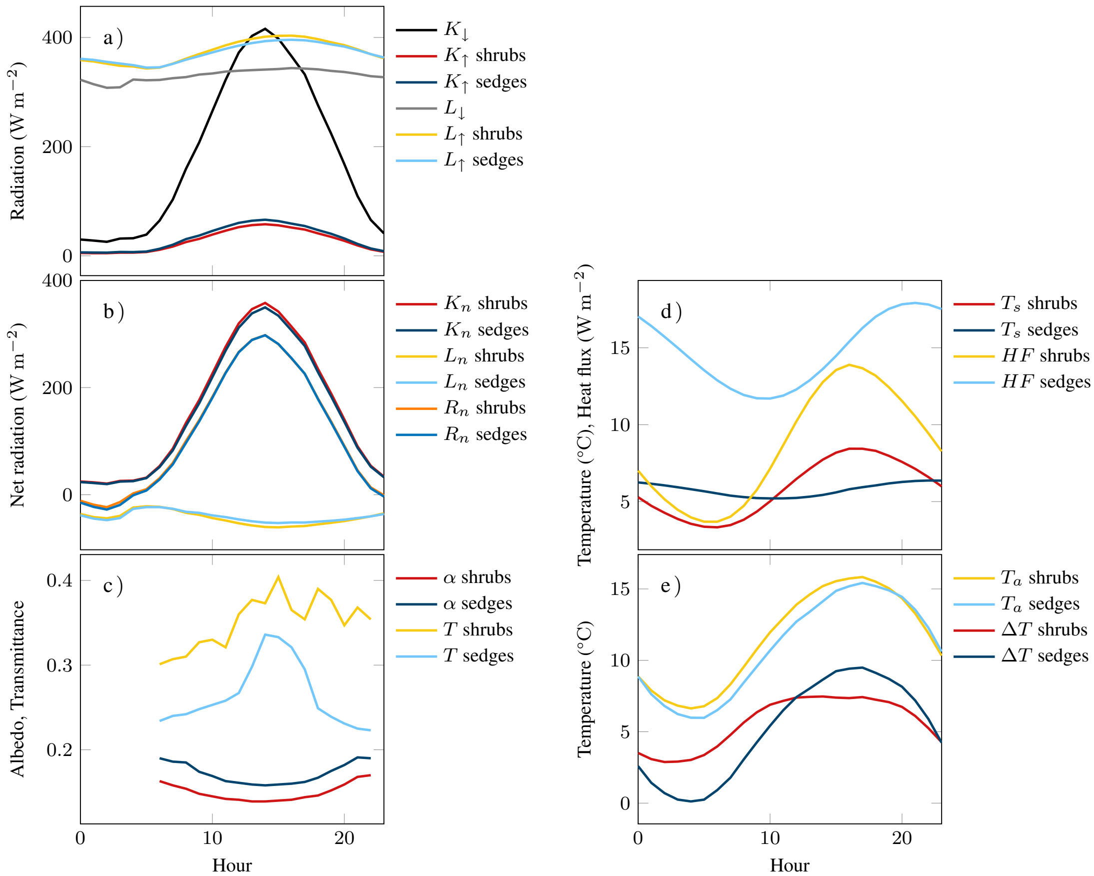

Fig. 1. For caption please see above

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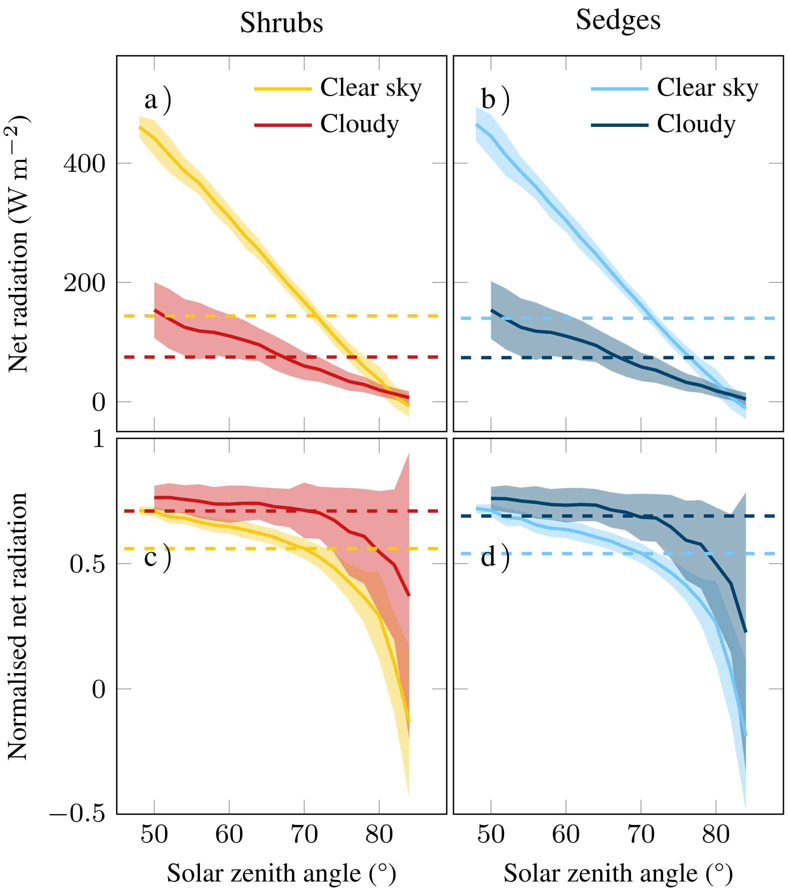

Fig. 2. For caption please see above