Reply to Reviewer 1

We are grateful to the reviewer for the thoughtful comments and suggestions to our manuscript. We have compiled a revised version and in the following provide a point-by-point reply to all issues raised. The reviewer's comments appear in bold font, our replies in normal font, and changes to the manuscript are in italics.

In this study the authors present a remote sensing based scheme for transient modelling of the ground surface regime together with the previously published numerical model CryoGrid2. The scheme is applied over a large area in the Lena River Delta (LRD), Siberia. Forcing datasets at 1km and weekly resolution are derived from MODIS LST, MODIS SCE, GlobSnow SWE plus meteo fields from ERA-Interim reanalysis. Spatially distributed ground properties are based on geomorphological observations and mapping drawing on previous studies in the region. Results are compared to insitu observations of ground temperatures from boreholes, CALM active layer depths and measurements from the Samoylov Island Permafrost observatory. The authors conclude that comparison to in-situ measurements shows that the scheme is capable of estimating the thermal state of permafrost and its time evolution in the LRD.

This paper is a further contribution to the work of using remote sensing data together with numerical models (eg. Westermann 2015) which I think is a very interesting and promising approach to large area and/or operational assessments. The paper is well written with a clear methodology, presentation of results and critical discussion. The authors acknowledge shortcomings of the approach such as dependency upon a well estimated snow density and difficulty in applying in heterogeneous terrain due to coarse scale of the LST data. I have one main comment with respect to the forcing timeseries, other comments are reasonably minor.

Comments:

1. **P8 Section 3.3: In the merged LST /reanalysis product, 2m air temperature and LST are merged. I think it would be helpful to add some discussion of how comparable surface air temperature and LST are and how this is expected to vary under both different atmospheric and surface cover conditions. The most obvious example is when a snowcover is present and air temperature and snow surface temperature can differ strongly. This reference (Gallo et al 2011) would probably be useful: http://dx.doi.org/10.1175/2010JAMC2460.1. This study from Raleigh et al. http://dx.doi.org/10.1002/2013WR013958 suggests that the 2metre dewpoint temp (also available from ERA-Interim) is perhaps a better approximation of snow surface**

temperature than 2m air temperature. What kind of biases can be expected by forcing the upper boundary condition of surface temperature with a 2m air temperature field? Or are these different forcings treated differently by the model?

We have taken up this comment in Sect. 3.3 and in the Discussion, Sect. 5.1.1. In Sect. 3.3, we have explained how we handle situations when positive temperatures of the surface forcing (which can occur as a result of admixing of air temperatures) occur for still snow-covered ground:

"During cloudy skies, differences between air and surface temperatures are strongly reduced compared to clear-sky conditions (Gallo et al., 2011), so that air temperatures can be regarded an adequate proxy when MODIS LST is not available due to cloud cover. For melting snow, surface temperatures are confined to the melting point of ice, while air temperatures can be positive. Positive values of the surface temperature forcing are therefore set to 0°C when a snow cover is present."

In-situ measurements on Samoylov Island indicate that air temperatures are a relatively good proxy for snow surface temperatures in winter, most likely because the ground heat flux from the refreezing active layer and the cooling permafrost is a substantial source of energy to the surface which prevents strong near-surface temperature inversions. In Sect. 5.1.1 we write:

"Based on in-situ measurements, Raleigh et al. (2013) suggest that for snow-covered ground dew point temperatures are a better approximation for surface temperatures compared to air temperatures at standard height. However, observations on Samoylov Island suggest only a small offset between snow surface and air temperatures, with the difference increasing from near zero in early winter to about 1° C in late winter (Table 3, Langer et al., 2011b). The reason for this is most likely that the ground heat flux is a strong heat source especially in early winter (Langer et al., 2011b) which warms the surface and thus prevents formation of a strong near-surface inversion. Therefore, we consider air temperatures an adequate proxy for snow surface temperatures in the LRD, but dew point temperatures should clearly be considered for gap-filling in the snow-covered season in future studies."

2. **P10 l20-22: is this spatial variability due to residual snow patches? Perhaps state the cause here.**

In July, residual snow patches do not occur on Samoylov Island, the snow pack has fully melted by at latest mid June – the spatial variability is caused by different surface cover and soil moisture conditions. Using a thermal camera, Langer et al. (2010) showed that the spatial differences in polygonal tundra can be up to 10K for single scenes, but become much smaller for temporal averages over longer periods. However, a residual net difference between the point measurements used for comparison and the larger-scale MODIS LST values cannot be excluded. Text changed to:

"However, surface temperatures can feature a strong spatial variability during summer due to differences in surface cover and soil moisture conditions…"

3. **P7 l3 + 33 on line 3 you say "extensive set of observations available" whereas on l33 you say "which temporally /spatially distributed sets are not available" - are these statements contradictory?**

An extensive data set is available from Samoylov Island, but there is no data set covering the entire Lena River Delta (which we refer to in the second statement). We have made this clearer in the text, l. 33 now reads:

"Therefore, the snow … is a highly crucial parameter for which spatially or temporally distributed data sets covering the entire LRD are not available. However, an extensive set of measurements from polygonal tundra on Samoylov Island suggests …"

Can you describe the snow density data briefly in Section 2.2, particularly at which times of year these measurements were made.

We have inserted a statement in Sect. 2.2:

"*In addition, a spatially distributed survey of snow depths and densities (216 points in polygonal tundra) was conducted in early spring 2008 (25 April to 2 May) before the onset of snowmelt (Boike et al., 2013*)."

In addition, the range of snow depths obtained from the spatial survey has been added to Fig. 3.

4. **Fig 6: Is there an offset in your measurements as looks like in Fig 6 that zero curtain is occurring 0.5deg or so below the 0degC point.**

Yes, there is a slight drift of the sensor in the later years (visible from 2010), with the zero curtain occurring at about -0.2°C instead of 0°C. A statement has been added to the figure caption.

5. **Fig 6: can you explain why there is no zero curtain at phase transition from ice to water in spring/summer in the wet polygon? Would you expect this?**

The zero curtain effect is a result of a two-sided freezing front which only occurs in fall for permafrost ground (the top freezes in fall and the ground below the active layer is permanently frozen). In this case, the temperatures at both sides of the still unfrozen domain are confined to 0°C due to the freezing of soil water at the freeze front. As a consequence, temperatures inside this domain quickly reach 0°C as well. As the freeze fronts progress slowly due to the considerable amounts of latent heat provided by the phase change of the water, this zero curtain state can last for several weeks and only ends when the two freeze fronts meet each other, which is generally followed by rapid cooling of the then frozen soil. In spring, the ground thaws from top down and only one freeze/thaw front exists. In this case, there is always a temperature gradient both above and below the progressing thaw front, so that temperatures in a certain depth/grid cell are never confined to 0°C for extended periods. For seasonally frozen ground, the situation is opposite and the zero curtain effect occurs in spring, when the seasonally frozen layer thaws from top down and from the bottom up, again resulting in two freeze fronts. In fall, only on freeze front exists, corresponding to the freezing of the ground from top down, so that no zero curtain effect occurs.

Technical issues:

1. **p6 l29: add terms in brackets after items in text so that equation is more easily understood.**

done

2. **P7 l6: ...LRD for which... → ...LRD which..**

   Changed to "for which we define"

3. **P9 l27-29: I think it is more common to use term "layers" when talking about vertical discretisation of model units?**

   Changed to "layers"

4. **P10 l16: Figure 2 seems to lose most bar elements upon printing (not digital form). Perhaps my printer issue - but check this.**

   We have tried printing Fig. 2, but did not encounter any problems.

5. **P10 l24: "well suited as input for ground thermal modelling" - qualify this statement with something like ", at least in homogeneous terrain".**

"at least in homogeneous terrain" added

6. **P11 l7 over a an → over an.**

Done, thanks!

7. **p11 l10 repeated word "cloudiness" → you mean snow?**

Yes, we mean snow cover. Thanks!

8. **P14 l32-33: qualify statement with something like 'in homogeneous terrain'.**

We agree, this statement is too general. In the revised version, we have made clear that it only applies to our study area in the LRD, and only to homogeneous terrain. The sentence now reads:

"*We conclude that surface temperatures synthesized from MODIS LST and ERA-interim reanalysis are an adequate choice for the purpose of ground thermal modeling in the LRD, at least in homogeneous terrain. However, it may introduce a slight cold-bias in modeled ground temperatures*."

9. P17 l11: had → hand.

Done, thanks!

10. p18 l8: ares → area.

Done, thanks!

New reference:

Langer, M., Westermann, S., Muster, S., Piel, K., and Boike, J.: The surface energy balance of a polygonal tundra site in northern Siberia Part 2: Winter, Cryosphere, 5, 509–524, 2011b.