Hydrol. Earth Syst. Sci. Discuss., 12, C4672–C4678, 2015
www.hydrol-earth-syst-sci-discuss.net/12/C4672/2015/

Hydrology and Earth System Sciences
Discussions

Interactive comment on "Near–surface air temperature and snow skin temperature comparison from CREST-SAFE station data with MODIS land surface temperature data" *by* C. L. Pérez Díaz et al.

C. L. Pérez Díaz et al.

carlos.p.diaz@gmail.com

Received and published: 5 November 2015

Reply to Reviewer #3:

First of all, we want to thank you very much for all your suggestions. These helped improve the manuscript considerably.

We appreciated the revisions and have addressed each of the comments.

The manuscript was completely rewritten. Additional information was added to more

than one section.

NOTE: All changes to the manuscript are highlighted in yellow.

General comments:

The paper compares MODIS skin temperature (LST) and near-surface air (Ta) and skin (T-skin) temperature from ground measurements under snow conditions. All comparisons of ground data with satellite data are useful, but the findings need to be weighted by the spatial and time representativeness of the data sets inter-compared and the limitations of each measurement technique. The paper is perhaps lacking a better discussion around these issues, and can be in my opinion largely improved.

Reply to General Comments: The objective of the paper was to validate in situ T-air and T-skin with MODIS LST using the data recorded from a meteorological station (CREST-SAFE) located in a cold climate suitable for snow studies. The findings presented are of interest because most MODIS LST validation studies have been done over snowless barren surfaces. Furthermore, CREST-SAFE presents a distinct advantage over other synoptic stations because it has the instrumentation to observe T-skin directly. This allowed for the direct comparison between in situ T-skin and MODIS LST. Additionally, meteorological parameters such as wind speed and cloudiness were incorporated in the study to explain the physical changes the snowpack undergoes through the winter, and how these make T-air and T-skin diverge. Typically, barren surfaces share a similar temperature to T-air. This allows for some researchers to validate remotely-sensed LST with T-air, in lack of surface radiance emission measurements to derive in situ LST. However, as it was shown in this study, T-skin (which is to be considered the "soil" surface by the MODIS signal when present) is not similar to T-air.

We realize that CREST-SAFE's specific conditions might not apply elsewhere. However, the fact that CREST-SAFE does provide continuous T-skin and T-air data does help provide insight on the T-skin – T-air interaction throughout the snow season to evaluate whether the assumption that T-air and T-soil remains true for snow-covered regions was correct. Additionally, since wind speed is recorded in an automated manner at CREST-SAFE and cloudiness is recorded continuously at the NWS offices next to the site, a multiple linear regression analysis was used to find if there is a relationship between T-diff (dependent variable), cloudiness (independent variable), and wind speed (independent variable) to better understand the T-air and T-skin interaction. The results indicated that T-diff is affected inversely by both independent variables.

Lastly, and perhaps more importantly, the statement the paper wanted to make was that it is not accurate to validate MODIS LST using in situ T-air in snow-covered regions by assuming that T-skin will be similar to T-air because that is not the case due to snow heterogeneity, cloudiness, wind speed, and T-air itself. In addition to the already known commonality of pixel resolution and land cover type. It would be ideal if more synoptic stations around the world collected continuous T-skin observations and made them public. This study could then be expanded and perhaps a way to derive T-skin from MODIS LST could be developed.

My specific concerns are:

1. The introduction is confusing regarding the remotely sensed LST and how it relates to Ta. For instance, the sentence 'Normally, LST satellite readings can be compared accurately to near surface air temperature because the algorithms have been developed this way' is quite confusing. What algorithms, the LST or Ta? I guess it means the Ta (and not the LST) algorithms using as proxy LST. Or, the use of the word 'suspicion'. If satellite LST fails to reproduce ground LST, it is because of the challenges of measuring LST over snowed surfaces, not because the try to reproduce Ta. Previous work cited seems related to exploiting LST as a proxy for Ta, given the current challenge to derive near-surface Ta from remote sensors.

Thank you. This is correct. The introduction was completely rewritten and these issues were addressed.

2. More information about the sensors and auxiliary data would be good. For instance,

cloudiness seems a critical variable in the study but until the very end of the article we do not get a hint of how it measured or estimated.

More information on the sensors and auxiliary data were provided in the revised version of the paper.

3. Given the large miss-match between the ground radiometer and the 1km MODIS footprint, the exact location of the MODIS inversion cell is of importance. From aerial pictures we can see that the terrain surrounding the ground location is a mixture of man-made objects, soil, and canopies. If the MODIS cell was including a relatively large fraction of canopy, that would be of importance to interpret the comparison findings, as the canopy can be in many occasions closer to the air temperature than to the soil skin temperature.

The MODIS inversion cell is closely centered to CREST-SAFE and does not include any forested cover region. It is composed of grassland, bare land, and some residential homes. It is representative of high latitude rural areas.

4. Wondering if CREST-SAFE left the IR radiometer operating also when snow was not present. If so, it will be very interesting to also compare before and after the snow period. Lack of good agreement for the non-snow conditions could hint a lack of representativeness of the radiometer location (compared with the MODIS footprint). Also, the switch from non-snow to snow conditions is typically difficult for the inversion algorithms, i.e., the same inversion is not applied in both conditions and identifying the presence of snow is critical for the remote sensing algorithm to perform well. This suggestion is indeed interesting and could perhaps be done in the future. The IR radiometer was turned off during the snowless periods for the two years observed in this study.

5. I do not think that there is any mention in the paper that all comparisons with the MODIS product are under clear-sky conditions (although cloud contamination happens often). In that sense, the study of the LST-Ta difference as function of cloudiness,

though of interest, it may not add much to the specific goal of the paper (which according to the introduction is to evaluate the remotely sensed LST). I do not think it is any surprise that the LST and Ta are further apart under clear conditions for the reasons well exposed in the paper. The same about the dependence in wind speed of the LST-Ta difference. Given that cloudiness is available, it may have been more interesting to study if some of the large observed differences in LST and ground skin temperature are related to cloud contamination in the MODIS product, and if so, try to filter the MODIS LST to remove those cases before analyzing the data. Yes, all observations used in this study were under clear-sky conditions.

6. Table 1 and 2 may need more thinking and discussion. Overall, Aqua LST agrees better than Terra, compared with the ground skin or air temperature (average correlations including both surface and air temperature of 0.78 versus 0.64, respectively). Given that, as far as I know, sensor and inversion algorithms are common for both platforms, the differences should be related to time overpass and period of the winter sampled, assuming that the ground radiometer operates without issues (Terra day and nighttime overpasses are more distinct due to its local times, while Aqua day and night distinction depends much more on the length of the day and time of the year).

Mean Absolute Differences and Biases between RS LST and in situ temperatures were now added to explain the differences and similarities between them. Results showed acceptable accuracy for the MODIS LST retrieval algorithm and that the MODIS LST is indeed representative of in situ T-skin is at CREST-SAFE when looking at Biases, which are the common measurement used for RS LST validation using the temperature based method.

7. Figure 3 clearly shows more scatter for the nighttime than for the daytime. For many surface conditions, better agreement is typically observed between satellite LST and ground data for nighttime, due to issues of daytime shadowing related to orography, thermal gradients due to insolation, and so. I am not sure how this will play over snow conditions, but I suspect that in this case the larger scatter for nighttime is partly due

to more cloud contamination and the likely difficulties of the cloud mask to operate properly without visible imagery.

Nighttime retrievals do have more scatter and this is due to the difficulties of the cloud mask to operate properly without visible imagery.

8. The discussion around the Figures 4 and 5 is somehow confusing. For instance, I do not see the relevance of stating that 'the fact that MODIS LST better resembles near-surface air temperature helps explaining the low correlation values between MODIS LST and the T-skin'. We use a pool of data under clear-sky conditions (so when T-skin is further away from Ta) to check that MODIS LST correlates worse with T-skin than with Ta, I do not see how the large T-skin – Ta difference explain the better agreement of Ta with MODIS LST. The goal is not that MODIS LST gets closer to ground T-skin because T-skin is closer to the Ta, but that MODIS LST can capture T-skin in all conditions.

The discussion for both figures was rewritten to better account for the suggestions stated by the reviewer. Nonetheless, it should also be mentioned that these large absolute differences can be attributed to emissivity biases due to the impacts on MODIS LST by the changes in the radiative transfer properties of the surface when the snow is melting, since in warmer months the snowpack usually has a wet snow layer at the surface during daytime that changes the emissivity of the snow surface. Thus, affecting the thermal infrared (TIR) brightness temperature (TB) which is used to retrieve MODIS LST. Furthermore, when discussing the radiative properties of the snow surface, while not uniform, the IR emissivity of snow is understood enough to compensate for its effects in the remote sensing of T-skin. At near-normal viewing angles, the RS TB can be as much as 1.5°C lower than the thermodynamic temperature at wavelengths around 13 μm. At the shorter IR wavelength window (3.5–4 μm), uncertainty in emissivity does not translate into uncertainty in temperature because of the nonlinear nature of Planck's function, but at longer wavelengths it does. Fortunately, the highest and unreliable uncertainties in emissivity are beyond the 10.5–12.5 μm atmospheric window that the MODIS LST SW algorithm uses for retrievals. Results from previous studies have shown that the differences between RS LST and T-skin have not been due to emissivity as much as: orographic effects, topography, topographic shadowing, and snow deposition. None of which affect the area that surrounds CREST-SAFE.

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 12, 7665, 2015.