Hydrol. Earth Syst. Sci. Discuss., 10, C4023–C4031, 2013
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Hydrology and Earth System Sciences Discussions
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Interactive comment on "Spatial patterns in timing of the diurnal temperature cycle" *by* T. R. H. Holmes et al.

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Received and published: 12 August 2013

We thank the reviewer for the thoughtfull comments. Below we respond to the comments as listed in C3025.

1) Page 6022 line 4. We keep in situ in lower case in accordance with HESS style guide.

2) Page 6024. Following the reviewers suggestion we replace Table 1 with Fig 1.

3) Page 6025. Although TMI has (occasional) observations up to 39N/S, we change the range of TMI to 38 N/S to be consistent with the officially reported geographic coverage.

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4) Page 6026 line 21. On the limitations of Ka-band data. The text is amended to read: ".. the linear relationship between Ka-band and LST does potentially break down under frozen soil conditions or during precipitation events. This leads to the formulation of two conditions for the Ka-band data. To avoid frost conditions Tkav must be above 260K, a rough estimate of Ka-band freezing point determined in Holmes et al. (2009). The spatial standard deviation of all Ka-band observations within a 0.25 degree gridbox is used as an indicator for measurement uncertainty; above normal sigmaKa is attributed to active precipitation (Holmes et al. (2013)). The second condition is therefore based on sigmaKaV; a gridbox average is rejected if sigmaKaV is more than 1 K above the annual mean for that gridbox.

5) Page 6031 figure 3. On the analysis of sampling effect. For the revised manuscript we have redone the analysis of the effect of sparse sampling to account for some new insights. First of all, what we are trying to do is to test the effect of sparse sampling on the determination of the timing of Ka-band DTC by using the Tnwp. In this analysis we do not account for noise in the actual Ka-band observations. More problematic is that we have to assume that the DTC model is perfect. However, since we know that the DTC is not a perfect fit for the NWP temperature in some areas, we find biases that may not appear in the actual Ka-band analysis. In the revised paper we have presented this limitation of the analysis by showing the results of two separate analyses. The first uses the NWP data 'as is' to test Ka-band sampling, assuming perfect DTC model and having no noise on the samples. This leads to a pronounced bias in the tropical zone with a latitudinal mean of 25 minutes (and 15 minute standard deviation). We attribute this bias to a mismatch between DTC model and TNWP diurnal. This bias does not affect the results of the NWP analysis, as there is no sampling limitation there. We further think that the DTC model does not have this mismatch with the actual Tka. Therefore, in the second analysis we corrected the Tnwp for the mismatch with the DTC model before sampling at Ka-band times. This results in little to no bias and low standard deviation, and represents our best estimate of the actual sampling effect.

Taking this new analysis (Fig 2), there is much less latitudinal variation in bias and the number of data days (see Fig. 3) have only a weak relationship with standard deviation (Fig 4). The number of observations per day plays a role too, but since we have applied a 4 obs/day minimum to assure a minimal constrained of the diurnal temperature cycle, the effect of this is limited in the present analysis. Only if the amplitude and diurnal minimum can be estimated a priori, would TMI suffice to determine the timing. If only AMSR-E at 1am/pm is available together with one morning/afternoon satellite, the number of data days with ascending and descending passes of both satellites would be the main limitation. We did test if the combination of TMI/AMSR-E/WindSat would suffice (these are all satellites that also carry an X-band radiometer). Fig 4 shows the results of these tests. Removing SSM/I from the analysis limits the number of data days considerably, and increases the latitudinal standard deviation.

We have added the following paragraph at the end of Sect. 4 to discuss the importance of the individual satellites for the analysis and the number of data days: "The exact thresholds applied in these four conditions are chosen to select the most optimal days for the analysis, without overly limiting the number of usable data days in a given time period. Still, the effect of these criteria on the number of usable days results in the need for a time period of a year to generate sufficient data days to compensate for the uncertainty in the satellite observations, particularly in the tropical and boreal zones with limited diurnal amplitude. The above considerations and conditions also justify the use of the five different satellites to estimate the timing of Ka-band. The AMSR-E satellite is crucial to satisfy condition (3) because of its observation close to the maximum of the diurnal at 1:30 PM. The WindSat and SSM/I satellites help constrain the early morning minimum and the afternoon cooling limb. The TMI observations increase the number of data days by helping to satisfy conditions (1) and (3), and are indispensable for the inter-calibration of the sensors."

6) Page 6035 figure 7c. On the Boreal forest anomaly. The main anomaly that needs an explanation is the delayed timing of NWP, and a diurnal change in emissivity has no part

in that. Cold conditions limit the number of data days because we remove days where the temperature drops below freezing. The cold conditions also limit the size of the diurnal amplitude, further limiting the number of days we use and reducing the signal to noise ratio. Following the above analysis, this should only increase the uncertainty, so it still doesn't explain the delay. Since MERRA outputs every hour, we can use a crude way of determining the timing by looking at the time of maximum temperature. This points in the same direction, with even slightly more delay in Northern regions. This is also clear from the new figure that shows examples of the overall diurnal temperature fit for different land surface types (see Fig 5, included in the revised paper.). If this is an anomaly in the Tnwp, the explanation should be found within the MERRA model formulations for diurnal heat balance in boreal areas, with long cool days and limited radiative forcing. Unfortunately, TIR observations were not available at those latitudes to further corroborate if this is a model problem or not.

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 10, 6019, 2013.

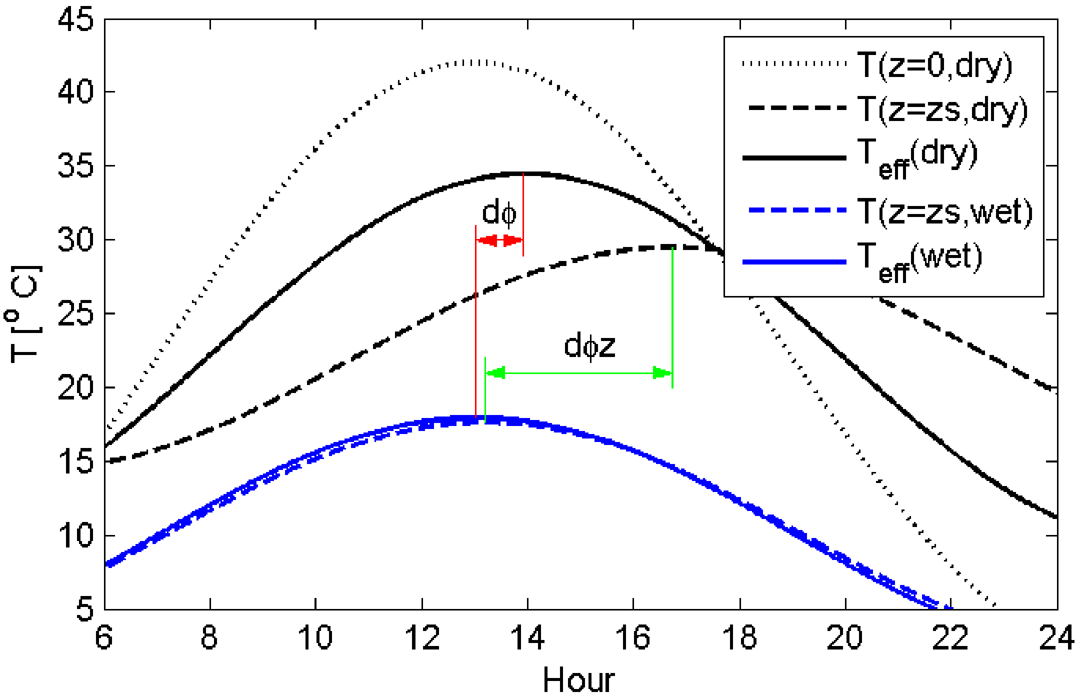

Fig. 1. Simulation of effective temperature for Ka-band emission for a dry (Teff(dry)) and a wet soil Teff(wet)). Assuming the shallow and deep layers are weighted equally in Teff(dry), The resulting

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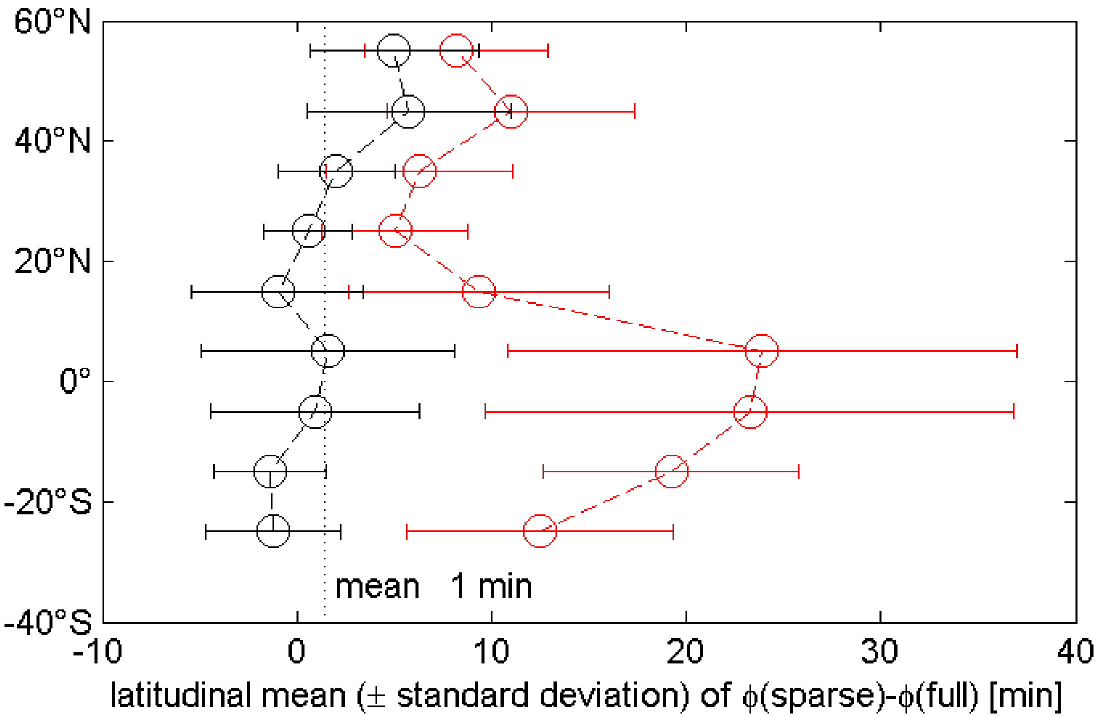

Fig. 2. Revised figure to replace Fig 3 in manuscript.

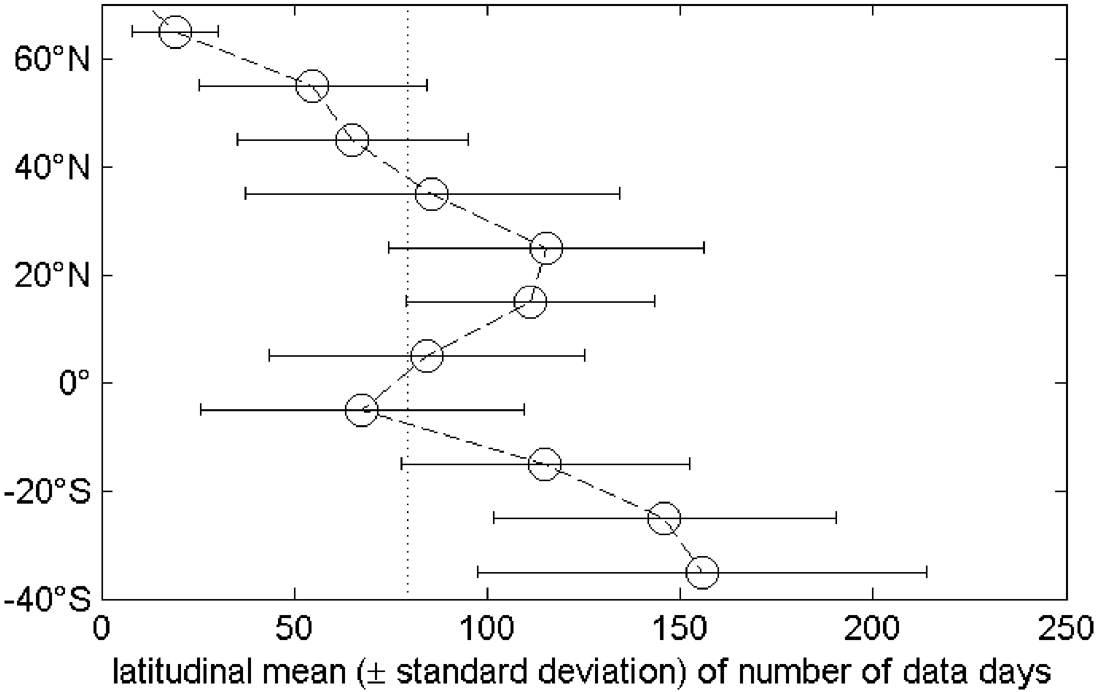

Fig. 3. Number of data days used in the analysis for the timing of Ka-band.

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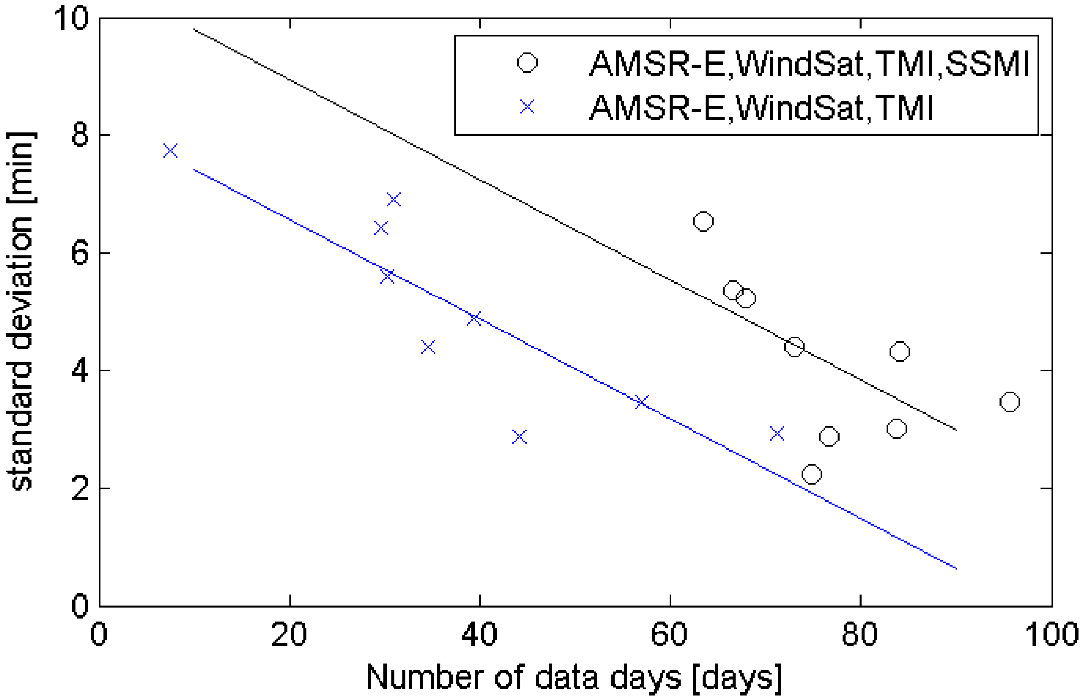

Fig. 4. Relationship of Number of data days on spatial standard deviation of sparse minus full timing results. Two cases are examined, one with all available satellites, and the other without SSMI.

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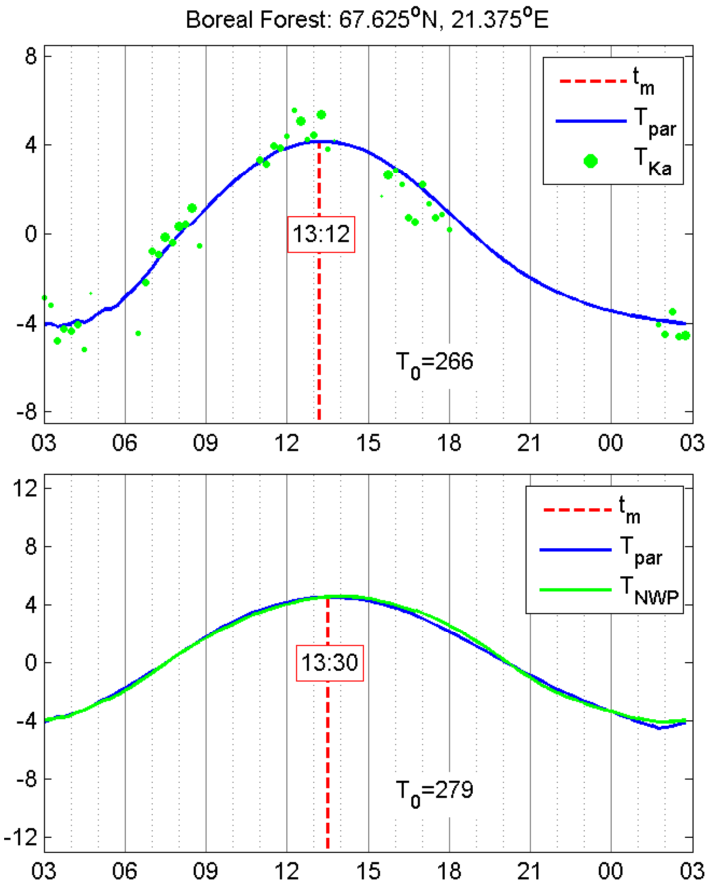

Fig. 5. Overall fit of the model (Tpar) to the three T estimates for selected locations. The displayed data reflects the annual average by hour of day.