Hydrol. Earth Syst. Sci. Discuss., 10, C4032–C4042, 2013
www.hydrol-earth-syst-sci-discuss.net/10/C4032/2013/

Hydrology and Earth System Sciences Discussions

Interactive comment on "Spatial patterns in timing of the diurnal temperature cycle" *by* T. R. H. Holmes et al.

T. R. H. Holmes et al.

thomas.holmes@ars.usda.gov

Received and published: 12 August 2013

We thank the reviewer for the thoughtfull comment. Below is our point by point response to the comments as listed in C3109.

1) P6020-L11. "In absolute terms" is used to contrast with the previously discussed "relative" spatial patterns. We add in the text that the average is over the Africa/Europe domain.

2) P6020-L13. Translation and context of timing difference in terms of T errors. The reviewer is right to question the impact of these relatively small changes in timing, especially between the NWP model and TIR. The reason we have refrained from commenting on it in the paper is that it is better discussed in the full context of differences

in amplitude between various measures of LST; the subject of a paper that is in preparation. The most general thing we can say is that an error in heat capacity resulting in 23 minute of timing difference, would also result in a 10 % reduction in amplitude according to heatflow equations as given in Holmes et al 2013: dA=exp(-dphi)=exp(-2*pi*(23/60)/24)=0.9045. In addition to this however, the offset itself affects the difference in temperature at any particular time. In the following example we simulated the effect of 23 minute phase shift for a T signal with an amplitude of 20 K, leading to +/- 1.4 K difference in temperature (see Fig. 1). For the purpose of data assimilation, this sort of harmonic behavior of structural errors is highly problematic. In Reichle et al. 2010 (citation in paper) this type of diurnal bias necessitated the formulation of a dynamic bias estimator with hourly bias terms.

To put these results into context for the reader, we have added the following discussion to the conclusion of the paper:

"To put this timing difference in context of biases in T, there are two main considerations. First, if this timing difference is a result of a too low heat capacity than the associated over-estimation of the diurnal amplitude would be 10 % for a 23 minute timing difference (Holmes et al 2012). Secondly, the timing difference will introduce a diurnal bias term. These two effects together result in a harmonic diurnal bias with an amplitude that depends on the diurnal temperature range (for example, 1.4 K bias for a T with 20 K diurnal range). This type of time-variant structural bias terms are much harder to account for in data assimilation approaches than constant bias terms."

And: "The presented analysis of the timing of the diurnal temperature cycle offers a means to account for these time-variant bias terms in a physically consistent way. With these maps we can now reconcile temperature records in terms of their diurnal timing, opening the way for studies that look at differences in diurnal amplitude and daily minimum, and ultimately for a global merger of temperature data.".

3) P6022-L2. Discussion of T errors. There is no doubt that the errors in LST estimates

are poorly defined, but this is true for the model as-well. The paragraph starts with a statement that '.. the relationship between different model and remotely-sensed based estimates of LST are poorly understood.' and proceeds with an explanation of why it is difficult to assess LST errors. In order to repeat more clearly that both observations and model estimates have problems, we insert the following:

"The resulting uncertainty regarding LST error characteristics is especially problematic when time varying structural errors go undetected. For remotely sensed LST estimates the bias may depend on emissivity, viewing angle, atmospheric opacity or sensing depth. In NWP models structural errors in LST may be introduced through the parameterization of the heat capacity, layer depth or estimation of surface energy balance components."

4) P6030-L21. Clear Sky. The main reason for clear-sky focus is that we want to avoid the effect of clouds on the solar radiation driven diurnal temperature cycle. A secondary reason is that the signal to noise ratio improves with increased diurnal amplitude, and clear skies have larger diurnal amplitudes. A methodological reason is that the DTC model we use represents clear-sky conditions, so it can only appropriately be applied to sparse data if the actual shape resembles the model. In the revised manuscript these points are now more clearly detailed.

5) P6031-L5. Sampling effect on TIR. In certain areas this may affect the estimated timing of TIR. However, by using a full year of data to calculate the timing we minimize this effect. Moreover, an analysis of seasonal values did not identify large seasonal differences, see also reply to comment below.

6) P6031-L23. Discussion of Ka-band timing maps: delay over tropics. The late peak of Ka-band over forest is indeed somewhat unexpected and following the reviewers suggestion we added this comment to the discussion of Figure 4A: 'More surprisingly is the delay in timing over the tropical forest, which cannot be attributed to sensing depth variation.'.

7) P6031-L28. Discussion of Ka-band timing maps: earlier timing over mountains. Indeed, the earlier phase over mountain regions is also observed in Tnwp, and to a lesser extent in Tir. We have moved the discussion of the mountainous regions to the description of the difference maps, where the azimuth effect of Tir is best discussed. And secondly, the overall earlier phase is discussed in the global maps as the large mountain ranges of the Himalaya and Andes show these patterns more clearly than the mountains in the Africa/Europe map. Below are the new paragraphs:

(In Discussion of Difference Maps) Areas with larger differences are found at the edge of land masses and mountain ranges, where phi_IR can be up to 1.5 h behind phi_NWP in Fig 5a. Interestingly, these areas also show up in Fig 5b, sometimes even indicating that TKa peaks earlier than TIR, which is not physically realistic. Because of this, we look to TIR for the explanation of these anomalies. Insofar these features line up with mountain ranges they are tentatively attributed to azimuth angle effects on TIR. Being retrieved from the geostationary satellite MSG-9 located at the prime meridian, the azimuth angle might explain the earlier phi over mountains to the North-West of the satellite, and the delayed phi over ranges that are to the East of the satellite. Such azimuth angle effects are muted within TKa as this is composed of observations with varying azimuth angles, and obviously play no role in the NWP record.

(In Global Results) Another feature that shows up is an earlier phi over mountainous or high elevation areas. Although this feature was discussed earlier, it is much more pronounced over the Andes and Himalaya. Since it appears in both TKa and TNWP it most likely reflects an actual pattern in diurnal heat exchange. Possible physical mechanisms for this include the effect of cooler air temperatures at higher elevation on sensible heat flux, diurnal patterns in orographic cloud formation, or slope effects on incoming solar radiation as described in Senkova et al. 2007.

8) P6032-L10. Delay in timing over tropical forest. The model is definitely predicting the later timing over the tropical forest well. We question however, if it is for the right reason. We know that the model has increased heat capacity for the tropical forest. It

is difficult to justify this for the thermal layer corresponding to TIR, and even Ka-band, and we therefore postulate a diurnal shape in cloudiness as the real cause for the delay in TIR timing. It may be that MERRA corrected for this by increasing the heat capacity, whereas it should have looked into diurnal distribution of the clouds. We make this reasoning more clear by adding a sentence to the relevant discussion:

“All sets have a delayed timing around the equator, which for TNWP is explained by the higher heat-capacity as parameterized for tropical rainforest. For TKa and TIR, with little to none penetration of the canopy layer, the delay in timing might more plausibly have to do with the effect of a diurnal pattern in cloudiness which can cause a delay in the peak solar radiation. If this is true, than MERRA predicts a correct delay in timing but for the wrong reason.“

9) P6032-L16. Boreal forest. The results over the boreal areas are interesting indeed. An important feature of the DTC shape over boreal areas is that the selection of days with minimum amplitude of 5 K limits the analysis to a small number of days with very long day length. The fit of the DTC model is not perfect in these circumstances, but if it introduces a bias it is actually underestimating the delay in timing. 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. In the revised manuscript we added the following statement: “ Since our analysis is restricted to days with minimum temperatures above freezing and a diurnal amplitude of 5 K or higher, the \phi calculated in these Northern regions with weak radiative forcing is based on a limited amount of long cool days. Unfortunately, TIR observations were not available at those high latitudes to positively attribute this anomaly to Tnwp.”

10) P6032-L18. Seasonality. We previously looked at seasonal subsets of the data to see if there are large variations in timing through the year, but didn’t find significant deviations from the annual mean (P6033, L 22-26). Fig B newly summarizes these

tests, showing for each 3-month period the seasonal average in color, compared to the annual average in black (as reported in the paper). There are small variations from the annual mean to comment on; for example it is interesting that in JJA the TIR anomaly is opposite of that of NWP in the Sahel latitudes, and opposite of Ka-band in the tropical zone. It should be noted that the reduced number of data days in this seasonal analysis increases the uncertainty, especially in the Northern latitudes where cold temperatures reduce the usable days further; the large positive anomaly shown for Ka-band in SON may be an artifact of this. Overall though, the seasonal anomalies are clearly small compared to the large-scale patterns that we discuss in the paper. Because detailed explanations for these seasonal deviations are beyond the scope of this work, we are hesitant to include this graphic in the paper, and will therefore keep the summary of this seasonal analysis in the Results section (P6033, L 22-26), with a slight modification to address the reviewers concern. “In order to test if the patterns in phi we find are stable through the year, the procedure to calculate phi was repeated for 3 month seasonal periods. The seasonal results confirmed the large-scale North South patterns as shown in Fig. 4d, giving confidence that land cover type is the main determinant for phi, rather than seasonal varying factors like soil wetness or cloudiness. Furthermore, it suggests that phi may be considered relatively constant in time; the spatial standard deviation of the seasonal anomaly from the annual phi is 6 min for Tnwp, 7 min for Tir, and 14 min for Tka.”

11) P6032-L21. The figures are now reordered.

12) P6033-L4. Discuss model fit. Orography is not all indeed, but it may explain a lot of the features that Fig 5a and 5b have in common, especially the marked SE-NW bands in the Middle East. Within the tropical zone there are more unexplained issues with TIR, particularly along the East and West coast of Africa; possibly the cloud filter was not strict enough there. The discussion of these figures will be sharpened a bit to more clearly separate the two main features; N-S pointing mountain ranges in 5a and 5b, attributed to Tir and explained by azimuth effects, and coast of Africa in the tropical

zone in both 5a and 5b, tentatively attributed to cloud issues in Tir. We don't think that the fit of the DTC model has a clear bearing on the azimuth or the cloud issues in Tir. The reason is that these issues showed up in Fig 5b (Tka Vs Tir); since both are observation based they should have the same bias relative to the modeled DTC. However, we do take the point that it is a possible cause of some structural bias in the results that might explain the reduced phi values of Tnwp along the coast. Although a detailed investigation of the effect of the diurnal shape would require a significant effort, we do include in the revised manuscript examples of the DTC fit for the four main surface types that are discussed; tropical, boreal, desert, and cropland (See Fig. 3). These figures show that although the fit is not perfect, it does not have a big effect on the bias, especially for Nwp and Tir with short sampling intervals. The underestimation of the temperature during the cooling down limb as is apparent in most plots can be significantly reduced by increasing k of Eq 2 by a factor of 2, or alternatively increasing the part of the cooling that is described by the exponential function. However, the effect that this had on the calculated timing was a spatially stable reduction in phi of about 7 minutes in both Tir and Tnwp. For Ka-band, there was more spatial variation of the impact on phi, with less reduction in deserts but slightly more in the tropical zone (up to 20 minutes earlier), having to do with the time of the fitting bias relative to the satellite observations. The overall RMS of the model fit with Tnwp could be reduced from 1.2 to as low as 1.1 K. To conclude, even though the improved fit does not have a big impact on the results of the presented timing analysis, more detailed regional analysis would benefit from relaxing some of the parameters that were fixed in this global study, especially ts and omega.

13) P6034-L12. Heat capacity over tropical forest. These are good questions. We did not find a discussion of the heat capacity of tropical forest in the literature. As for MERRA, presumably the modelers adjusted the heat capacity to account for detected mismatches with TIR.

14) P6035-L13. The paragraph is reworded and avoids the use of “absolute”.

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

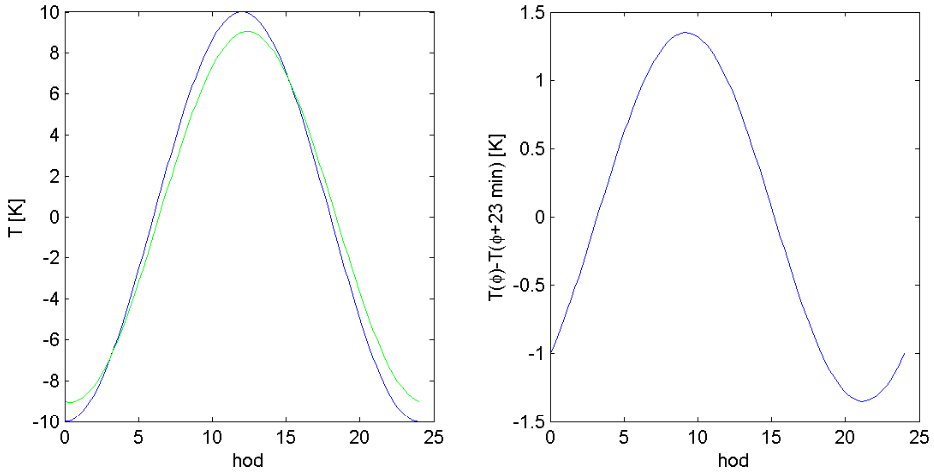

Fig. 1. Simulation of effect of phase difference on DTC.

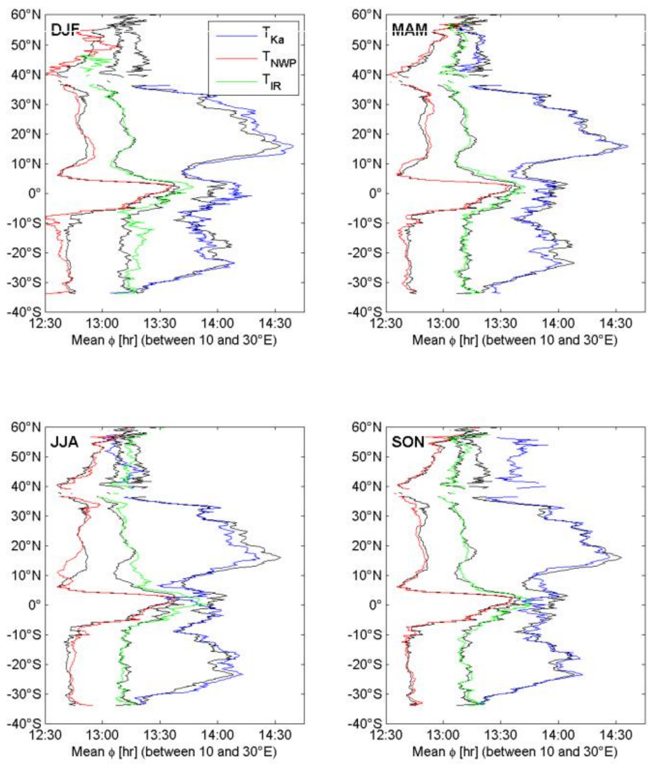

Fig. 2. North south transects of average phi, repeated for 3-month periods.

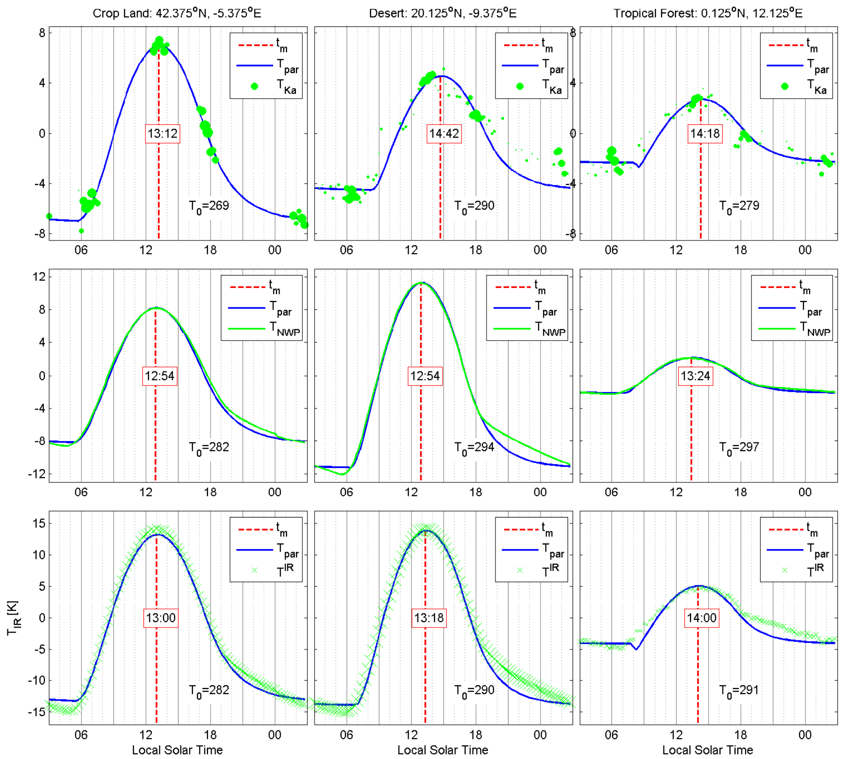

Fig. 3. Overall fit of the model (Tpar) to the three T estimates for selected locations. The displayed data reflects the annual average by hour of day.