Inconsistencies in the estimation of land surface temperature from longwave radiation measurements

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Land surface temperature (LST) is an important variable that controls the energy and water exchange between the Earth's surface and the atmosphere. It is widely used to estimate evapotranspiration and vegetation water stress through surface energy balance models. On a large scale, LST is obtained from space-borne instruments (remote sensing) consisting of radiometers measuring the thermal radiance from the underlying surface. On the other hand, at plot scale, flux towers record longwave radiation, which can be used to estimate LST locally. The up-welling and down-welling longwave radiation measured by radiometers mounted on the eddy covariance towers can be inverted to deduce LST using the Stefan-Boltzmann law and longwave balance (Eq. 1):

\[ L^\uparrow = \varepsilon \sigma T_s^4 + (1 - \varepsilon)L^\downarrow \] (1)

where \( L^\uparrow \) = upwelling longwave radiation (Wm\(^{-2}\)), \( L^\downarrow \) = downwelling longwave radiation (Wm\(^{-2}\)), \( \varepsilon \) = surface emissivity, \( T_s \) = surface temperature (K) and \( \sigma \) = Stefan-Boltzmann constant (Wm\(^{-2}\)K\(^{-4}\)).

Since down-welling longwave radiation was not measured routinely for a long time, the second term in Eq. 1 is commonly omitted, arguing that emissivity is close to unity and therefore Eq. 1 can be approximated by Eq. 2:

\[ L^\uparrow = \varepsilon \sigma T_s^4 \] (2)

Even with the availability of down-welling longwave measurements it is very common to use Eq. 2. This gives rise to the query if the simplified equation is adequate to estimate LST from flux tower measurements. Another question associated with this method is how to obtain the correct surface emissivity (SE) values needed for LST retrievals.

The present work addresses these two important issues by using FLUXNET data for different land cover types (mulga, tropical savanna, and eucalyptus forest). SE was estimated by comparing measured sensible heat flux (H) with estimated radiometric surface-air temperature difference (\( \Delta T \)) and assuming that \( \Delta T=0 \) if \( H=0 \) (Holmes et al., 2009). Our FLUXNET-based estimate of LST and SE was compared with space-borne measurements (MODIS). We found that LST values obtained using Eq. 1 were more strongly correlated with MODIS (MOD11) estimates, compared to Eq. 2. However, the SE derived using Eq. 1 was much lower than the MODIS emissivities, whereas surface
emissivity based on Eq. 2 was very close to the MODIS values. Generally, we found that, even at the high emissivity values taken from MODIS, the estimated LST values differed significantly (2 K or more) between the two equations for all ecosystems.

Considering that Eq. 1 physically correct equation, whereas Eq. 2 is an approximation, our analysis suggests that results based on Eq. 2 are likely biased and should be considered with caution. It further questions the implication of large scale SE at plot scale.

References: