A Review of the Physics for Emissivity Correction of Infrared Temperature Measurements

Appropriate correction for target emissivity is required for accurate surface temperature measurements. However, the simple correction that is commonly made, dividing the measured temperature by the target emissivity, is incorrect because it does not account for reflected radiation. Some infrared radiometers have an emissivity dial that makes this correction or it is done in software. Campbell & Diak (2005) suggest this type of simple correction is a holdover from the days when infrared radiometers were used to measure the temperature of molten metal in furnaces.

The radiation detected by an infrared radiometer includes two components: 1) the radiation directly emitted by the target surface, and 2) reflected radiation from the background. The second component is often neglected. The ratio of the two components in the radiation detected by the radiometer is weighted according to the emissivity (ε) of the target surface:

$$E_{sensor} = \varepsilon \cdot E_{target} + (1 - \varepsilon) \cdot E_{background} \tag{1}$$

where E_{sensor} is the radiant energy [W m^{-2}] detected by the radiometer, E_{target} [W m^{-2}] is the radiant energy emitted by the target surface, $E_{background}$ [W m^{-2}] is the radiant energy emitted by the background (when the target surface is outside the background is generally the sky), and ε is the ratio of non-blackbody radiation emission (actual radiation emission) to blackbody radiation emission at the same temperature (theoretical maximum for radiation emission). Unless the target surface is a blackbody ($\varepsilon = 1$; emits and absorbs the theoretical maximum amount of energy based on temperature), E_{sensor} will include a fraction $(1 - \varepsilon)$ of reflected radiation from the background.

Since temperature, rather than energy, is the desired quantity, Eq. (1) can be written in terms of temperature using the Stefan-Boltzmann Law, $E = \sigma T^4$, which relates the energy being emitted by an object to the fourth power of its absolute temperature:

$$\sigma \cdot T_{sensor}{}^4 = \varepsilon \cdot \sigma \cdot T_{target}{}^4 + (1 - \varepsilon) \cdot \sigma \cdot T_{background}{}^4 \tag{2}$$

where T_{sensor} [K] is the temperature measured by the infrared radiometer (brightness temperature), T_{target} [K] is the surface temperature of the target, $T_{background}$ [K] is the brightness temperature of the background (usually the sky), and σ is the Stefan-Boltzmann constant (5.67 x 10^{-8} W m^{-2} K^{-4}). Rearrangement of Eq. (2) to solve for T_{target} yields the equation used for ε correction of the measured brightness temperature. This equation yields the corrected target temperature:

$$T_{target} = \sqrt[4]{\frac{T_{sensor}{}^4 - (1 - \varepsilon) \cdot T_{background}{}^4}{\varepsilon}}\,. \tag{3}$$

Equations (1) – (3) assume an infinite waveband for radiation emission and constant ε at all wavelengths. These assumptions are not valid because infrared radiometers do not have infinite wavebands (most correspond to the atmospheric window of 8 to 14 μm), and ε varies with wavelength. Despite the violated assumptions, the errors for ε correction with Eq. (3) in environmental applications are negligible because a large proportion of the radiation emitted by terrestrial objects is in the 8 – 14 μm waveband, ε for most terrestrial objects does not vary significantly in the 8 – 14 μm waveband, and the background radiation is nearly always a small fraction (1 – ε) of the measured radiation. To apply Eq. (3), the brightness temperature of the background ($T_{background}$) must be measured or estimated with reasonable accuracy.

On clear days when the background temperature (generally sky temperature, T_{sky}) is cold compared to the target, the simple correction (dividing the measured temperature by the target ε) reduces the error, but does not eliminate it (Fig. 1). If T_{target} and $T_{background}$ are equal (e.g. on a cloudy day), no ε correction is necessary because the reflected radiation equals the fraction of radiation not emitted (1 – ε) by the target (the fraction 1 – ε is the longwave reflectivity of the target surface). In this case the simple ε correction over-corrects and results in a temperature higher than the actual target temperature (Fig. 1). To apply Eq. (3) where the sky is the background, sky brightness temperature can be measured with an infrared radiometer or pyrgeometer (longwave sensor), or estimated with a model. Although the ε of a fully closed canopy can be 0.98-0.99 (Campbell & Norman 1998), the lower ε of soils and other surfaces can result substantial errors (Fig. 1). The errors for an ε greater than 0.98 should be less than 1.0 °C.

Campbell G.S. & Norman J.M. (1998) *Environmental Biophysics*. Springer-Verlag, New York, NY, USA.

Campbell G.S. & Diak G.R. (2005) Net and thermal radiation estimation and measurement. In *Micrometeorology in Agricultural Systems*, (eds. Hatfield J.L. & Baker J.M.), pp. 59-92. American Society of Agronomy, Madison, WI, USA.

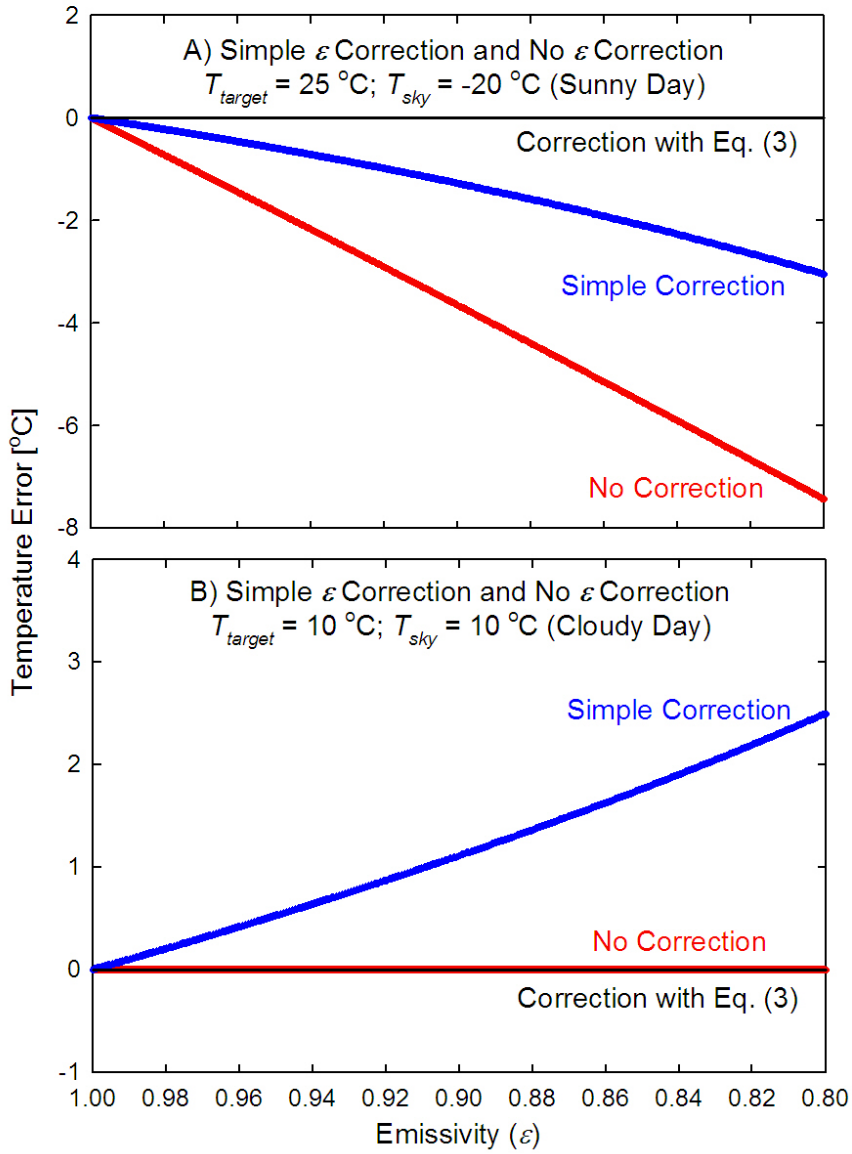

Figure 1. Comparison of simple emissivity (ε) correction and no ε correction, where simple ε correction is dividing the measured temperature (surface brightness temperature) by the target ε, which does not account for reflected radiation from the background. A) On sunny days when the background sky temperature (T_{sky}) is much colder than the target temperature (T_{target}), simple correction yields a T_{target} value closer to the actual temperature, but because it does not account for the reflected radiation $(1 - \varepsilon)$ coming from the sky, it under-corrects for target ε. B) When T_{sky} and T_{target} are equal then ε correction is not necessary because the reflected radiation from the sky equals the exact amount of the fraction $(1 - \varepsilon)$ of radiation that would have been emitted if the target were a blackbody. Under this condition simple correction causes over-prediction of T_{target}. Correction with Eq. (3) yields the correct value of T_{target}.