EGU2020-11804
https://doi.org/10.5194/egusphere-egu2020-11804
EGU General Assembly 2020

Remote Quantification of Land Surface Temperature and Evapotranspiration Using Thermal Infrared Observations from Unmanned Aerial Systems

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Thermal infrared (TIR) remote sensing has a wide array of applications in the environmental sciences, but such applications often require absolute temperature estimates with a high degree of accuracy. Low cost microbolometer-based imaging sensors present a possible alternative for such applications, being lightweight enough for deployment on small Unmanned Aerial Systems (UASs), and thus potentially opening up a new range of applications requiring high spatial or temporal resolution and flexible flight planning. These sensors however lack temperature stabilization of the imaging focal plane array (FPA), prohibiting the reliable retrieval of absolute temperature. Here we present a radiometric calibration methodology developed in laboratory settings using a temperature-controlled chamber and programmable blackbody, allowing for independent control of sensor and target temperatures. These laboratory data provided the basis for linear calibration equations that account for both mean and non-uniformity corrections of the FPA raw radiance counts, as a function of ambient sensor operating temperature. Multiple independent experimental trials were used to extensively validate the algorithm in the laboratory, demonstrating a retrieval error of less than 1 degree Celsius. The calibration methodology was tested under realistic field conditions during a two-day field campaign that utilized ground-based observations of land surface temperature (LST) for both a collection of ground targets with a range of reflectance / emissivity properties, and agricultural plots in Northern California. These field experiments included the deployment of the uncooled microbolometer imaging sensor on a UAS, with acquisitions made throughout a highly variable diurnal period. These UAS experiments demonstrated the effectiveness of the pre-flight calibration methodology under field conditions with excellent agreement between retrieved LST and ground-based infrared thermometers for both homogeneous tarps (R^2 = 0.95) and heterogeneous vegetation plots (R^2 = 0.69 across all crop types), with the full range of target temperatures spanning approximately 15-60 degrees Celsius throughout the campaign. The prediction error for absolute temperature estimates of field targets was found to be within 1 degree Celsius, within the range considered acceptable for many vegetation monitoring applications. We further present results of the application of these UAS-based remote measurements of LST to quantify evapotranspiration (ET) for multiple crop systems.

UAS flights were conducted over wheat, soybean and maize fields throughout diurnal periods during the growing season of each crop. LST observations were integrated into the Surface Temperature Initiated Closure (STIC) biophysical evapotranspiration model to estimate ET. Validation against eddy covariance system estimates of evapotranspiration (latent energy flux) shows high predictive accuracy ($R^2 > 0.95$).