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How to Represent Thermal Radiation Anisotropy for Improving Surface Flux Retrieval from Surface Temperature Measurements?

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This work examines the sensitivity of the retrieval of surface energy balance (SEB) fluxes to the directional characteristics of thermal measurements. When considering remote sensing measurement of surface temperature in different sun-target-sensor geometries, it is expected that flux estimates should remain consistent regardless of whether they are retrieved from nadir or off-nadir observations. In order to characterize the impact of the measurement geometry, our working hypothesis is that directional effects are primarily driven by the repartition of sunlit vs. shaded surfaces in the field of view of the radiometer.

The analysis focuses on three modelling frameworks:
- the SPARSE model based on a two-source scheme as TSEB (Boulet et al. 2015)
- the SPARSE4 model based on a four-source scheme separating sunlit and shaded surfaces (Mwangi et al 2022)
- the SCOPE model based on a detailed description of the exchanges and the distribution of temperature within the canopy (van der Tol et al. 2009, Duffour et al. 2015, Yang et al. 2021)

SPARSE and SPARSE4 were applied to estimate surface fluxes while simultaneously assessing potential directional biases. A controlled experimental configuration was adopted by relying on simulations from the SCOPE model (as previously proposed in Duffour et al. 2015). These simulations provided reference conditions representing a continuum of homogeneous vegetation states, ranging from sparsely vegetated and water-stressed surfaces to dense, well-irrigated canopies. The flux components simulated by SCOPE were treated as reference values for the inversion and evaluation of the retrievals obtained from thermal infrared using SPARSE and SPARSE4 models. In a first step, SPARSE/SPARSE4 flux estimates derived from nadir brightness temperatures were compared against these reference simulations. The comparison indicates that both formulations reproduced the main surface fluxes with generally satisfactory agreement.

In a second step, the angular stability of SPARSE/SPARSE4 retrievals was examined by comparing the deviation of the derived latent heat flux in different viewing geometry to the flux estimated from nadir measurements. Example of results are provided in Figure 1. In general, retrieved flux presented underestimation that increased with the solar zenith angle, but this effect was significantly lower for SPARSE4 than for SPARSE. Underestimations were also limited in situations with limited directional anisotropy due to surface uniformity, in particular at the lowest investigated LAI (1). By contrast, intermediate canopy leaf area conditions exhibited more pronounced angular inconsistencies. Further analysis highlights the dominant role of incoming solar radiation, especially near midday, in driving these differences. Wind speed and vegetation water status also contribute to the observed variations, although to a lesser extent. Soil moisture conditions appear to influence the results mainly in sparsely vegetated environments. When canopy density increases, the soil thermal contribution to the radiation escaping the canopy becomes negligible, which reduces its impact on directional effects.

Overall, the extended SPARSE4 configuration improves the robustness of the retrievals and tends to reduce directional inconsistencies across most simulated scenarios, particularly as canopy cover becomes more extensive. Finally, the potential implications for thermal remote sensing from polar-orbiting satellites are considered. Sensors operating within relatively narrow viewing geometries present only limited impact of directional thermal anisotropy, while sensors presenting large swath, in general for improving revisit, may be subject to higher impact.

The results presented in this study only considered homogeneous canopies, but it is worth noting that Mwangi (2022) developed different version of the SPARSE4 model that be used for non-homogeneous canopies such as vineyard and orchards (Mwangi et al. 2022 and 2023). These versions also present improvement in the retrievial of latent heat flux from directional measurements.

All these results support the hypothesis of the use of sunlit/shaded proportion of surfaces within the canopy as a first driver of thermal infrared anisotropy.

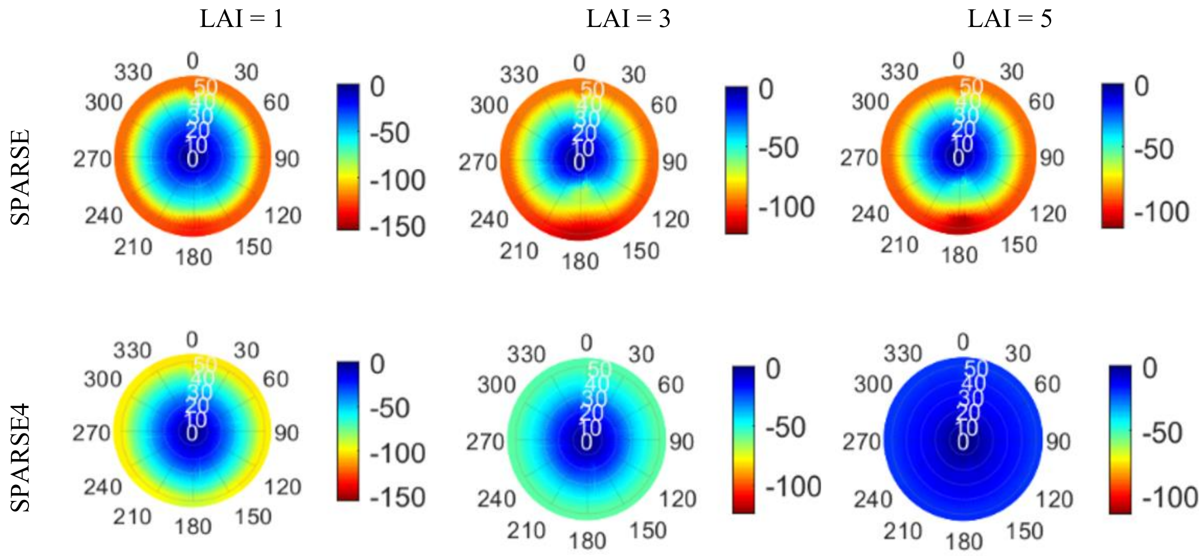

Figure 1. Exemples at 3 different LAI level of latent heat flux retrievals from surface temperature in different viewing geometries using SPARSE and SPARSE4. Data are in W m^{-2}.

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