EVALUATION OF TWO KERNEL-DRIVEN MODELS FOR ESTIMATING DIRECTIONAL BRIGHTNESS TEMPERATURE IN THE THERMAL INFRARED

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ABSTRACT

Directional anisotropy limits the application of land surface temperature (LST) and a simplified parametric model to effectively estimate directional brightness temperature (DBT) in the thermal infrared is critical. This study used a widely validated four-stream scattering by arbitrarily inclined leaves (4SAIL) model as a benchmark to evaluate the performance of the kernel bidirectional reflectance distribution function (BRDF) model and the three-kernel-model. Results showed that the two kernel-driven models can fit the DBT well and the maximum root mean square error (RMSE) is 0.13°C. The kernel BRDF model has a wider application scope including canopies of uniform, spherical, plagiophile and planophile LIDF with low LAI and hotspot. When LIDF is planophile and plagiophile, two models can reach the best fitting effect and the worst effect is the canopy with erectrophile LIDF. Under a specified LIDF, the relationship between fitting accuracy and LAI is negative while hotspot parameter is positive.

***Index Terms*—**DBT, 4SAIL model, kernel BRDF model, three-kernel-model

1. INTRODUCTION

Land surface temperature (LST), an indispensable parameter of the land surface energy budget, is widely used in climate change, evapotranspiration, urban heat island studies and other fields [1-3]. However, this key parameter has been prone to own significant directional anisotropic behavior. Temperatures under different viewing angles are different and this difference can even reach up to 15°C which greatly restricts the application of LST [4]. Therefore, determining a proper model to estimate the directional brightness temperature (DBT) and normalize it to a reference direction is an urgent and meaningful work.

Previous studies of modeling DBT can be roughly classified into two categories: the radiative transfer model and the parametric model. Radiative transfer models, such as four-stream scattering by arbitrarily inclined leaves (4SAIL) [5] and soil canopy observation, photochemistry and energy fluxes (SCOPE) model [6] , are derived from complex physical basis and can obtain accurate DBT. However, these models need many input data and are time-consuming, which makes it difficult to apply them in calculating DBT directly and efficiently. Whereas, parametric models are more attractive owing to their simplicity. Modeling DBT as a linear combination of some kernels which are trigonometric functions of the observation geometry is the most common way. For example, Peng et al. [7] has proved the kernel-driven bidirectional reflectance distribution function (BRDF) model can simulate the DBT well with multi-angle thermal infrared images, and Vinnikov et al. [8] developed a three-kernel model to evaluate the angular anisotropy of LST using one full year of geostationary satellite observations.

Compared with satellite observation and experimental measurement, simulation data can provide a large number of DBT values under different situations which is the key to evaluate a model. For this reason, we used the widely validated 4SAIL model as the data generator to compare two kernel-driven models – the kernel BRDF model and the three-kernel-model in detail. The details of these three models will be present in section 2, and results and the discussion will be shown in the section 3 and section 4 respectively.

2. MODLES

2.1 Radiative transfer model 4SAIL

The 4SAIL model extended the four-stream radiative transfer formalism of the scattering by arbitrarily inclined leaves model to the TIR domain by adding the internal thermal radiation [5]. This updated version divided the canopy into sunlit and shaded soil and sunlit and shaded leaves to simulate top-of-canopy (TOC) thermal radiances of different viewing angles. It can also analyze influences of leaf area index (LAI), leaf inclination distribution function (LIDF) and hotspot effect on TOC thermal radiances. The 4SAIL model has been widely validated and used in calculating DBT, directional emissivity and component temperatures [9, 10].

2.2 Kernel-driven models

2.2.1 Kernel BRDF model

The kernel BRDF model was firstly proposed to simulate bi-directional reflectivity under different viewing angles. Because thermal radiation and optical radiation have some similarities, such as the volumetric multiple scattering and influences of the solar position, the kernel BRDF model can also be used in estimating DBT by replacing reflectivity with DBT [7]. In this paper, we used the kernel group of Ross-Thick volume kernel and the Li-SparseR geometry kernel which has the best fitting effect, and the formulation are written as follows:

$$T(\theta_v,\theta_s,\varphi) = f_{iso} + f_{vol}\cdot k_{vol}(\theta_v,\theta_s,\varphi) + f_{geo}\cdot k_{geo}(\theta_v,\theta_s,\varphi); \quad (1)$$

$$k_{vol}(\theta_v,\theta_s,\varphi) = \frac{(\pi/2-\xi)\cos\xi + \sin\xi}{\cos\theta_v + \cos\theta_s} - \frac{\pi}{4}; \quad (2)$$

$$\cos\xi = \cos\theta_v\cos\theta_s + \sin\theta_v\sin\theta_s\cos\varphi; \quad (3)$$

$$k_{geo}(\theta_v,\theta_s,\varphi) = O(\theta_v,\theta_s,\varphi) - \sec\theta_v' - \sec\theta_s' + \frac{1}{2}(1+\cos\xi')\sec\theta_v'\sec\theta_s'; \quad (4)$$

$$O(\theta_v,\theta_s,\varphi) = \frac{1}{\pi}(\mathrm{t}-\mathrm{sintcost})(\sec\theta_v' + \sec\theta_s'); \quad (5)$$

$$\mathrm{cost} = \frac{h}{b}\frac{\sqrt{D^2 + (\tan\theta_v'\tan\theta_s'\sin\varphi)^2}}{\sec\theta_v' + \sec\theta_s'}; \quad (6)$$

$$D = \sqrt{\tan^2\theta_v' + \tan^2\theta_s' - 2\tan\theta_v'\tan\theta_s'\cos\varphi}; \quad (7)$$

$$\cos\xi' = \cos\theta_v'\cos\theta_s' + \sin\theta_v'\sin\theta_s'\cos\varphi; \quad (8)$$

$$\theta_v' = \tan^{-1}(\frac{b}{r}\tan\theta_v) = \theta_v; \quad \theta_s' = \tan^{-1}(\frac{b}{r}\tan\theta_s) = \theta_s \quad (9)$$

where $T(\theta_v,\theta_s,\varphi)$ is the DBT; θ_v, θ_s, φ, f_{iso}, f_{vol}, f_{geo}, k_{vol}, k_{geo} are the viewing zenith angle, solar zenith angle, relative azimuth angle, the isotropic scattering kernel coefficient, the volumetric kernel coefficient, the geometric kernel coefficient, the volumetric kernel and the geometric kernel, respectively; the ratio $\frac{h}{b}$ and $\frac{b}{r}$ are the dimensionless crown relative height and shape parameters, and preselected as 2 and 1 in this paper.

2.2.2 Three-kernel-model

Vinnikov et al. [8] developed a three-kernel model to normalize LST to the nadir direction using two geostationary satellite observations at five surface radiation stations. The model can be expressed by the following simple equation:

$$\mathrm{T}(\theta_v,\theta_s,\varphi)/\mathrm{T}_0 = 1 + A\cdot\varphi(\theta_v) + \mathrm{D}\cdot\psi(\theta_v,\theta_s,\varphi) \quad (10)$$

$$\triangle\mathrm{T}(\theta_v,\theta_s,\varphi) = \mathrm{T}_0(A\cdot\varphi(\theta_v) + \mathrm{D}\cdot\psi(\theta_v,\theta_s,\varphi)) \quad (11)$$

$$\varphi(\theta_v) = 1 - \cos(\theta_v) \quad (12)$$

$$\psi(\theta_v,\theta_s,\varphi) = \sin(\theta_v)\cos(\theta_s)\sin(\theta_s)\cos(\theta_s-\theta_v)\cos(\varphi) \quad (13)$$

where T_0 is the temperature at nadir direction, 1, φ, ψ, A, D are the isotropic kernel, emissivity kernel, solar emissivity, emissivity kernel coefficient and solar emissivity coefficient, respectively. Currently, this model has been applied to correct Satellite-derived LST from directional anisotropic effect [4].

3. RESULTS AND DISCUSSION

We used the same input parameters of 4SAIL model as Peng .et al [11] owing to this situation has been validated with ground measurement. Different canopy structures were created by prescribing 6 LIDF (erectophile, extremophile, spherical, uniform, plagiophile, planophile), 6 LAI (0.5, 1, 2, 3, 4, 5) and 4 hotspot parameters (0.01, 0.05, 0.1, 0.5). For each of them the viewing zenith angle from nadir to 60° and azimuth angle from 0 to 360° by step of 1°. Thus, the simulated dataset is composed of 144 cases and every case has 21600 angle groups.

The least square method was used to fit two kernel-driven models and root-mean-square error (RMSE) was selected as the evaluation index. As the figure 1 shows, the maximum RMSE of these two kernel model is less than 0.14°C, and the proportions of RMSEs under 0.02°C are 65.97% and 75%, respectively. This high accuracy indicates that both the kernel BRDF model and the three-kernel-model can fit the DBT well.

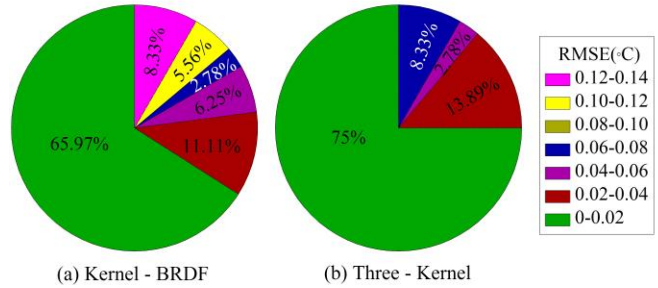

Figure 1. DBT fitting accuracy of two kernel-driven models. (a) for kernel BRDF model and (b) for three-kernel-model.