Calculation of TIR Canopy Hot Spot and Implications for Earth Radiation Budget

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ABSTRACT

Using a 3-D model for thermal infrared exitance and the Lowtran 7 atmospheric radiative transfer model, we compute the variation in brightness temperature with view direction and, in particular, the canopy thermal hot spot. We then perform a sensitivity analysis of surface energy balance components for a nominal case using a simple SVAT model given the uncertainty in canopy temperature arising from the thermal hot spot effect. Canopy thermal hot spot variations of two degrees C lead to differences of plus or minus 24% in the midday available energy.

INTRODUCTION

The use of remote sensing to improve estimates of sensible and latent heat and other components of the surface energy balance offers many practical applications for agriculture and resource management. Many Soil Vegetation Atmosphere Transfer (SVAT) models are partly driven by satellite observations or are calibrated using such measurements. Several researchers now employ data assimilation methods using combined ground and satellite observations [1].

All of these methods rely on accurate estimates of satellite-derived surface temperature, and much attention has been given to atmospheric correction methods, use of Normalized Difference Vegetation Index (NDVI) versus Temperature (T) relationships for refinement in sparse canopies, and determination of optimum look angles considering simple directional anisotropy effects. In this paper, we look at a new, relatively unexplored aspect: the canopy thermal hot spot [2,3]. Lagouarde, et al. illustrate hot spot variations in the solar principal of 2 deg C for a pine canopy as measured from an aircraft platform. Balick and Hutchinson report tower results from a leafless deciduous canopy exhibiting strong thermal differences between the canopy over and under story and the litter background. Strong asymmetric heating of tree trunks was evident with angular variations of 3 to 5 deg C.

We perform a theoretical calculation of the canopy thermal hot spot in the solar principal plane for a vegetation canopy using a three-dimensional thermal infrared exitance model we previously have developed and compared with measurements [4]. We estimate additional uncertainty induced by atmospheric directional variations using Lowtran 7 [5]. Finally, we compute resulting uncertainties for various components of the surface energy balance for a nominal case. Further examples will be given during the presentation.

METHOD

We simulated a fairly continuous canopy 20 m by 20 m on a side with a Leaf Area Index of 3.0. The test scene contained 388,800 leaf facets randomly selected from a spherical leaf angle distribution. Leaf facet size was 5 cm by 5 cm. The canopy was 0.8 meters tall, and we selected a view point 10 meters above the canopy. Given this geometry, the total field of view of the canopy was 70 degrees, i. e. plus or minus 35 degrees from zenith.

Table 1. Scene geometry and meteorological parameters

Meteorological	Vegetation
Wind speed (4 m s^{-1})	Height (0.8m),
Relative humidity (55%)	LAI (3.0)
Short-wave flux (915 W m^{-2})	Spherical Leaf Angle
Air temperature (27.5 C)	Area of 20 m x 20 m

Support was provided by the NASA Earth Observing-1 Mission Instrument Performance Evaluation and Data Validation Program and, in part, by the U.S. Army Engineer Research and Development Center, Modeling and Simulation Initiative.

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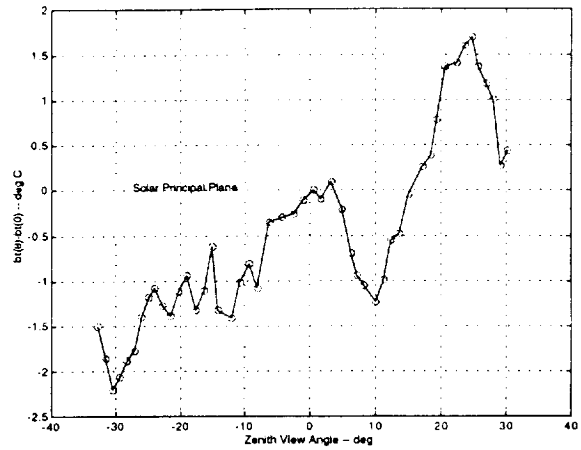

Fig. 2 Difference in brightness temperature with zenith view angle and nadir along the solar principal plane.

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We selected meteorological conditions, shown in Table 1, corresponding to late morning with a solar zenith angle of 24 degrees and solar azimuth of 146 degrees, measured clockwise from North. Fig. 1 shows a visual simulation of the scene using a hemispherical projection out to 35 degrees. The solar principal plane lies along the diagonal line with nadir indicated by the center dot. The solar reflective hot spot can be seen in the upper left position along the principal plane. Sun position is in the lower right.

As outlined in [4], we first use ray tracing to determine the sunlit and shaded leaf surfaces within the canopy and then solve the resulting energy budget equations to determine the corresponding leaf temperatures. Sunlit temperatures ranged from 24 to 32 deg C with warmer temperatures occurring more frequently. Shaded leaf temperature was 26.5 deg C.

Subsequently, we positioned a viewer 10 m above the canopy and projected 70,000 rays towards the canopy along the solar principal plane. The rays were distributed plus or minus 35 degrees from zenith in equal angle increments, .001 deg. For each ray we computed the thermal infrared exitance projected into the field-of-view. We then averaged the data to one degree bins by summing the contributions from 1000 rays within each one degree bin.

RESULTS

In order to reduce small-scale variations in the ray-traced results, we subsequently applied a moving average filter to the data with 5 deg width. Following Lagouarde, et al. [2], we converted the data to apparent brightness temperature and plot the differences between off-nadir and nadir directions. The results are shown in Fig. 2.

The canopy hot spot effect is clearly evident. We obtain over a 2 deg C peak corresponding to the zenith view angle 24 degrees in the anti-solar direction. The width of the canopy hot spot is significant and likely diagnostic of canopy geometry, but we have not yet explored this aspect.

For comparison, we performed a simple experiment over an unmowed lawn canopy using an Omega Scope 2000A (8-14 micrometer) thermal infrared sensor. Solar zenith angle was 45 degrees. Measurements in the solar principal plane indicated a canopy thermal hot spot of nearly 4 deg C variation between the solar and anti-solar azimuths.

Analysis with Lowtran [5] corresponding to the conditions corresponding to our simulation yielded results similar to Lagouarde [2]. For zenith view angles up to 25 degrees an additional uncertainty of 0.5 deg C are induced by atmospheric effects.

Finally, using the approach outlined by Kustas, et al. [6] and our SVAT model described in [4], we obtain uncertainties in the midday available energy of plus or minus 24% corresponding to a 2 deg C variation in estimated surface temperature for the conditions described in Table 1.

CONCLUSIONS

We have illustrated the use of a three-dimensional canopy thermal infrared exitance model to compute the at-surface canopy thermal hot spot variation. Resulting computed surface kinetic temperatures can be used in atmospheric radiative transfer codes to estimate the at-sensor variation in canopy temperature.

Next the uncertainty arising from the canopy thermal hot spot variation was used, together with a simple SVAT model, to indicate the resulting variation in surface energy balance for a nominal case.

Only illustrative calculations are given in this short paper. A potential limitation in the present study was our omission of multiple scattering for the thermal infrared flux [7]. We expect this effect to be small for the case simulated but need to repeat our analyses explicitly including it. Our ray tracing code readily accommodates multiple scattering but requires more processing time.

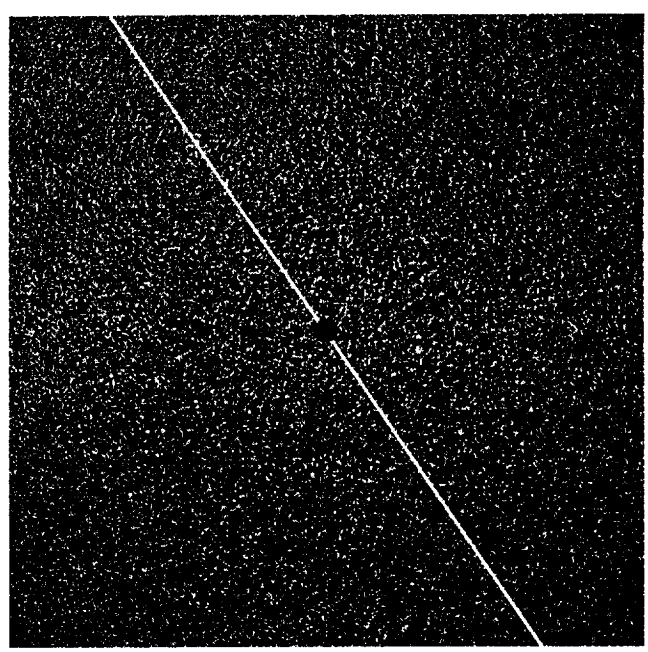

Fig. 1 Simulated visual image of the test scene. The solar principal plane is indicated by the diagonal line and nadir by the center dot.

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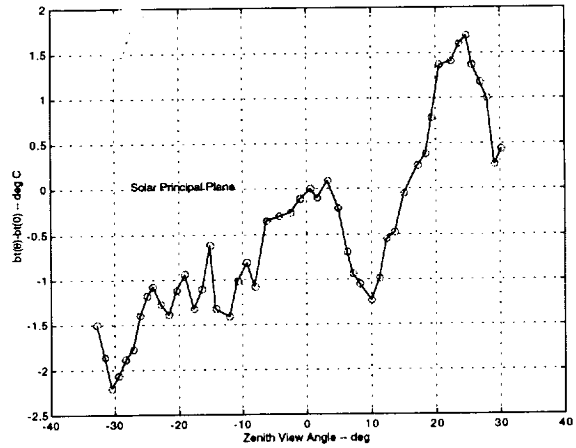

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