Evaluation of the Isotropy Assumption for Longwave Radiation Using Satellite Data

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Introduction

Although the anisotropy of shortwave radiation reflected from the earth's surface has been examined and accounted for in a number of studies (e.g., Minnis and Harrison 1984), it is common to assume that surface-emitted longwave radiation does not change considerably based on angular and topographical variations. However, recent studies have documented that measured infrared brightness temperatures can deviate based on a number of characteristics, including viewing zenith angle (VZA) and vegetation cover. Wong et al. (1996) used PRT-5 data as well as Geostationery Operational Environmental Satellite (GOES-8 and GOES-7) data to illustrate the magnitude of this difference on a large scale, as well as the possible azimuthal effects on the observed infrared (11 mm) brightness temperature differences (BTD); variations of up to 5 K over a mountainous forested region were detected using the multi-angle view satellite data. At a smaller scale, Lagourde and Kerr (1993) measured brightness temperatures from a detector 2 m above various surface types. That study revealed surface type- and VZA-dependent BTD up to 8 K. Whereas some studies have developed models to account for some of these differences (e.g., Sobrino and Casselles 1990), the dependence of brightness temperature on azimuthal angle, VZA, solar zenith angle (SZA), terrain type, and vegetation cover has not been adequately determined from observations or characterized in models. Failure to take into account these variations and their relationship to angular and surface characteristics could result in significant errors in estimated outgoing longwave radiation (OLR) and the true skin temperature. This paper further explores the anisotropy of clear-sky brightness temperature and the potential effect on the OLR.

Methodology

GOES-7, GOES-8, and GOES-9 datasets from various cloud-free days during three Unmanned Aerospace Vehicle (UAV) experiments during 1995-1997, as well as selected days in February 1998, were used for this study. The data were sectioned into 2° x 2° boxes for the purposes of intercomparing only data with similar angular characteristics. Within these boxes, the data were further subdivided into 10' boxes classified by International Geosphere Biosphere Programme (IGBP) vegetation type. A separate average infrared (IR) brightness temperature was calculated for the western (135° W) and eastern (75° W) GOES satellites, per 2° x 2° box, SZA, and vegetation type. The BTD between the eastern and western GOES satellites were computed and plotted against time (UTC) and SZA to determine terrain and angular effects on IR brightness temperature (TCS). To correctly use these two datasets, the GOES-8 and GOES-9 brightness temperatures must be compared along 105° W longitude, the midpoint of the two satellites. One such comparison, from selected days during September-October 1997, reveals a warm bias of approximately 0.5 K in the GOES-8 data, similar to differences found by Wong et al. (1996) for GOES-8 and GOES-7 data. For the current study, these differences are left uncorrected but should be considered when comparing the datasets.

Results

A plot of GOES-8 and GOES-9 brightness temperatures for October 4, 1997, reveals curves that peak around local noon, with the GOES-8 curve peaking approximately 1 hour earlier than the GOES-9 curve (Figure 1). A close examination of these two temperature curves shows a striking

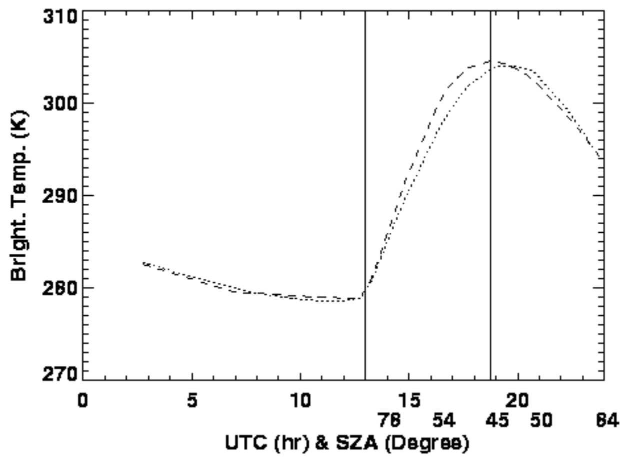

Figure 1. Plots of GOES-8 (dashed) and GOES-9 (dotted) Ch. 4 brightness temperature, from 2° by 2° box with northwest corner 41° N 102° W, October 4, 1997 (scene type 14, Crops/Mosaic). Vertical lines denote approximate time of sunrise, noon, and sunset, respectively.

difference; the curve of GOES-8 - GOES-9 brightness temperature differences reveals a peak in the morning, and a minimum in the afternoon (Figure 2). The morning peak and afternoon minimum are characteristic of the differences for many of the areas studied. The temperature differences are typically more pronounced for mountainous terrain than for flat terrain. A regional average of BTD near Baja, California, reveals a nearly flat cycle throughout the day for water, in contrast to the other two scene types on land (Figure 3). To illustrate the impact these variations in

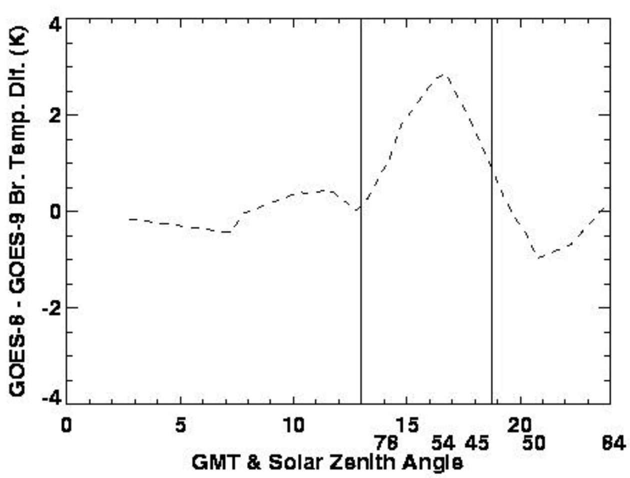

Figure 2. The difference (GOES-8 - GOES-9) of the two curves from Figure 1.

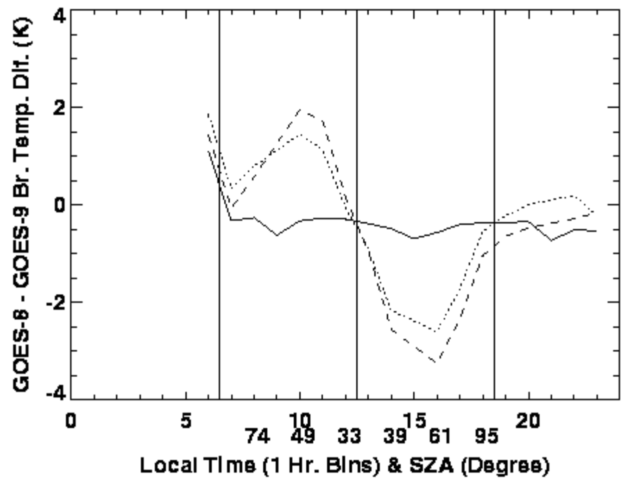

Figure 3. Differences in Ch. 4 GOES-8 and GOES-9 brightness temperature, averaged into 1 hourly local time bins, for the region 22° N through 26° N, 112° W to 108° W from 1345 UTC February 22 to 2345 UTC February 23, 1998. Vegetation types represented are Open Shrubs (dashed), Crops (dotted), and Water (solid).

brightness temperature could have in an estimation of OLR, calculations of this quantity (after Fu and Liou 1993) were made using GOES-8 and GOES-9 brightness temperatures throughout one day (Figure 4). The curves show that the

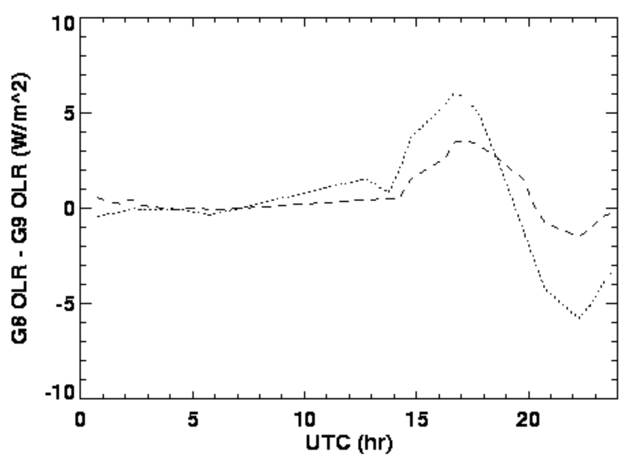

Figure 4. Differences in OLR derived from Ch. 4 GOES-8 and GOES-9 brightness temperature on February 23, 1998. Dotted line denotes OLR difference for mountainous land (24° N 104° W northwest corner of 2° by 2° box.); dashed line denotes flat land (29° N 99° W northwest corner of 2° by 2° box).

two satellites yield differences up to approximately 7 W/m^2 in OLR for the mountainous data, and 3.5 W/m^2 for the flatter terrain.

Discussion

The anisotropy of TCS is driven by a variety of factors such as shadowing, surface heat capacity and surface emissivity. The portion of scene receiving the most sunlight will warm fastest, while the most shaded portion should remain the coolest. The anisotropy of reflected solar radiation over land provides one measure of shadowing. For example, the maximum reflectance generally occurs at the antisolar point, while the minimum reflectance occurs at the angles for which shadowing is greatest. Figure 5 shows a scatterplot of mean BTD and differences in bidirectional reflectance anisotropic factors from Minnis and Harrison (1984) between GOES-8 and GOES-9. Two 2° x 2° regions of averaged 10' data classified as grassland are shown, with one region representing mountainous terrain (24° N 104° W), and the other representing relatively flat terrain (29° N 99° W). The respective linear correlation coefficients are 0.93 and 0.88. The slope of the mountain line is approximately three times that for the flat land, suggesting that the greater shadowing induced by the mountain causes greater angular variation in the surface temperature. The differences in the reflectance anisotropy account for 86% and 77% of the variance, respectively, indicating that they can serve as a basis for modeling the angular dependence of

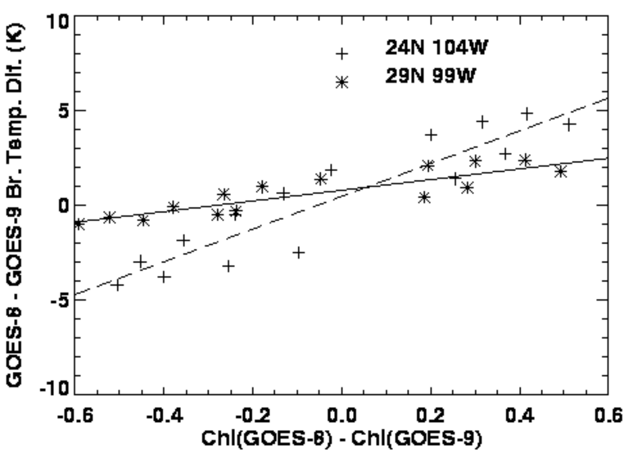

Figure 5. Differences in bidirectional reflectance anisotropic function (Chi) vs. differences in GOES-8 and GOES-9 brightness temperature from 1415 UTC to 2345 UTC, February 23, 1998. Dotted line denotes mountainous land (24° N 104° W northwest corner of 2° by 2° box.); dashed line denotes flat land (29° N 99° W northwest corner of 2° by 2° box).

BTD. The remaining scatter may be due to VZA-dependent surface emissivity, the range of SZA, atmospheric attenuation and the vegetation type. One of the limitations of using only GOES data is the restricted angular configuration. For instance, the north side of any scene in the northern hemisphere cannot be seen by a geostationery satellite. Thus, the temperature of most shadowed parts of many scenes cannot be measured.

Conclusions and Future Work

The results show that land surface brightness temperatures are extremely dependent on the viewing and illumination conditions, and are dependent on vegetation type to a smaller degree. The OLR calculations based on GOES-8 and GOES-9 brightness temperatures measured at the same times show a significant difference; thus, there are potential ramifications if anisotropy is inadequately dealt with when using satellite measurements to derive OLR. To avoid uncertainty in derived land skin temperatures and OLR calculations, further quantification of this behavior is needed. Strict definition of mountainous and flat terrain must be made in order to determine the true impact of these characteristics on the data. Also, measurements of the same area from more than one viewing zenith angle must be used; where possible, this will be undertaken with satellites in non-geostationery orbits and aircraft data, in addition to the GOES data used in this study. Correction for VZA-dependent emissivity and atmospheric attenuation must also be applied. Models can then be developed to account for the variations.

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