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DETERMINING THE RELATIONSHIP BETWEEN THE TOTAL AND WINDOW CHANNEL NIGHTTIME RADIANCES FOR THE CERES INSTRUMENT

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1. INTRODUCTION

Observing Earth's radiant energy budget from space is critical to improving our understanding of Earth's climate system. The Earth Radiation Budget Experiment (ERBE) (Barkstrom 1984; Barkstrom and Smith 1986) was the first initiative to provide simultaneous observations of Earth's radiant energy with identical instruments flying aboard separate satellites. The design of the ERBE instrument was based upon three complementary broadband radiometers which measured the shortwave (< 5 µm), longwave (> 5 µm), and total regions of the spectrum. Since any two of the ERBE radiometers could be used to simulate the third, a three channel intercomparison, based on redundancy, was available to uncover any changes in the relative sensitivities of the individual radiometers. Such a three channel intercomparison thus provided confidence in the application of the ERBE measurements over the lifetime of the instrument while mitigating the concern over instrument degradation.

When the Clouds and the Earth's Radiant Energy System (CERES) (Wielicki et al. 1996) instrument was designed, the longwave channel was replaced by an 8 to 12 µm infrared window channel. While such a substitution allowed for improved measurements of the radiant energy budget near the Earth's surface, the straightforward ERBE-like three channel intercomparison was sacrificed. Characterizing the stability of the CERES instrument, however, is critical to understanding the measured radiances from CERES. Thus, we have undertaken an investigation to determine whether conditions exist wherein the CERES window channel measurements can accurately yield a one-to-one representation of broadband longwave radiances. We initiated the present study by obtaining CERES nighttime (i.e., darkside of the earth) measured radiances for the window and total channels for the first seven months of 1998. The nighttime total channel radiances are, of course, directly related to broadband longwave radiances. An examination of the CERES data reveals a highly correlated linear relationship between the window and total channel measurements for conditions corresponding to deep convective clouds. With the establishment of that relationship between the CERES window and total channel measurements, and thus a relationship between the CERES window channel measurements and broadband longwave radiances, we have been able to formulate a three channel intercomparison for the CERES instrument which is analogous to the ERBE three channel intercomparison.

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2. COMPARISON OF WINDOW TO TOTAL CHANNEL AT NIGHT

An examination of the nighttime radiances measured by the CERES instrument aboard the Tropical Rainfall Measuring Mission (TRMM) spacecraft has revealed a positive correlation between the window and total channel measurements. For most atmospheric conditions, however, the regression between the window and total channels produces considerable variance and thus the correlation is not sufficiently precise to allow for accurate simulations of one channel from the other. Nevertheless, for the case of deep convective clouds (DCC), there exists a highly correlated linear relationship between the window and total channel measurements. To understand this relationship, a series of theoretical calculations using a line-by-line algorithm (Kratz and Rose 1999) were run to simulate the top of atmosphere (TOA) spectral radiances representative of conditions observed by CERES/TRMM. The line-by-line calculations demonstrate that for the DCC case, the spectra of the outgoing radiances are dominated by Planck blackbody emission (see Figure 1). As a result, both the window and total channels measured radiances have contribution functions that represent nearly the same altitude regions in the atmosphere. The consequence being that measurements from one channel can reliably predict measurements from the other. In contrast, for clear sky or low cloud conditions, the outgoing TOA radiances for the window and total channels could often characterize different altitude regions in the atmosphere. Since the two channels were measuring radiances originating from different altitudes, there is no surprise that one channel could not accurately simulate the other for non-DCC conditions.

The functional form of the relationship between the window and broadband longwave radiances has been determined by regressing the nighttime window channel measurements against the nighttime total channel data for the same footprints. To achieve the best fit with our regressions, we needed to sort the nighttime data by specific geo-physical scene type and limit the geo-loca-

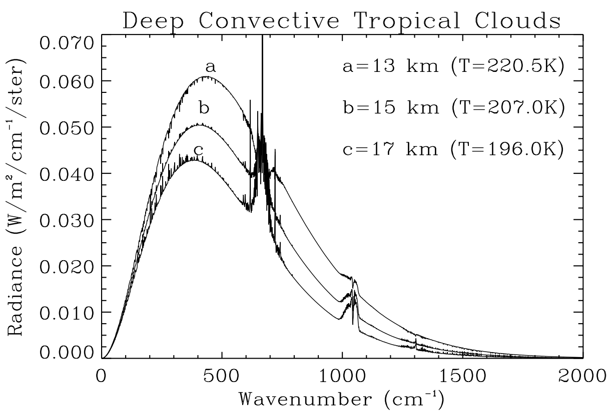

Figure 1. *Outgoing spectral radiances for deep convective clouds in the McClatchey et al. (1972) tropical atmosphere. The top curve corresponds to the lowest and warmest clouds, while the bottom curve corresponds to the highest and coldest clouds. As the effective emission temperature falls, the peak of the emission curve shifts noticeably to shorter wavenumbers (longer wavelengths).*

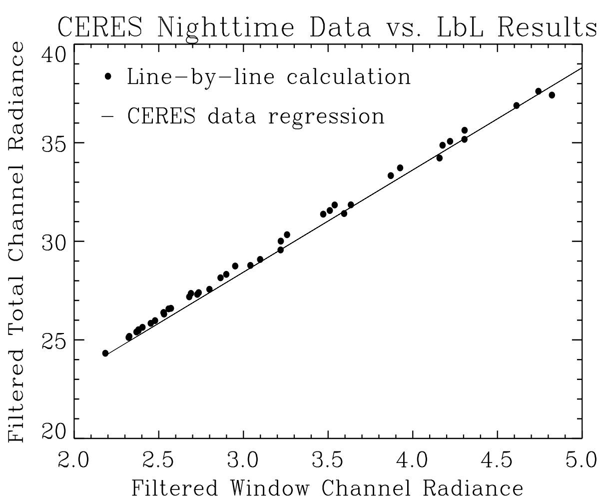

Figure 2. *Comparison of the regression fits of the CERES measurements (solid line) to the line-by-line calculations (filled circles) for the nighttime conditions of deep convective clouds (DCC).*

tion to ±20° latitude. We then produced regression fits representing the relationship between the filtered window and filtered total channel measurements for each of the seven months from January through July, 1998. Since the functional forms of the regression fits are very similar for each of the seven months, only the average fit is shown in Figure 2

In order to illustrate the comparison of theory with measurements, the theoretical results from the line-by-line calculations are also presented in Figure 2. The comparison of the theoretical results to the measurements yields very good agreement, although theory does tend to exceed the measurements by about 1-2%. While the source of this discrepancy could either be in the theoretical calculations, the window channel measurements, or the total channel measurements, the greatest uncertainty lies with the spectral response function of the total channel (see Figure 3). A comparison of

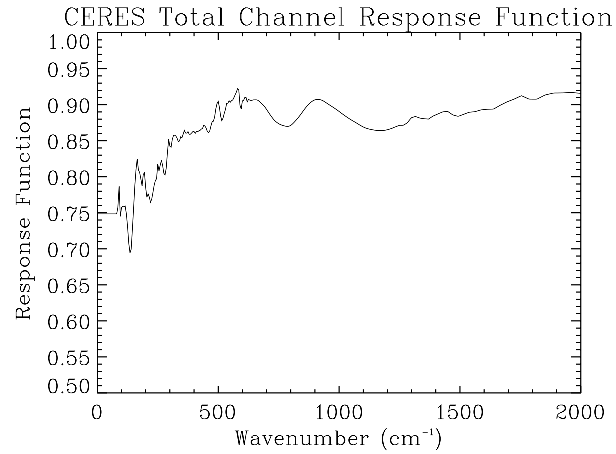

Figure 3. *The spectral response function for the thermal infrared region of the CERES/TRMM total channel.*

Figures 1 and 3 clearly illustrates that as the effective emission temperature decreases the emission curve shifts to smaller wavenumbers where the total channel spectral response is no longer flat. Thus, when deep convective clouds are considered, it is critical to have an accurate representation of the far-infrared portion of the spectrum. Unfortunately, the far-infrared (>20 μm) portion of the total channel response function is not as well measured as the visible (0.4-0.7 μm), near-infrared (0.7-5 μm) and mid-infrared (5-20 μm) portions. Thus, the 1-2% discrepancy between theory and measurement leads us to question the accuracy of the far-infrared measurements of the total channel spectral response function. Indeed, our results suggests that the accepted values for the CERES total channel response function might be too high in the far-infrared portion of the spectrum.

To further complicate matters, the tropical mean (TM), which is the average of all the nadir longwave data in the tropics over ocean, yields a CERES total channel nighttime measurement that is about 2% higher than the equivalent nighttime measurement from the Earth Radiation Budget Satellite (ERBS) scanner. The source of this discrepancy may well come from the CERES or ERBS instruments or actual changes in the radiative state of the tropics. While the calibration of the CERES instrument is almost certainly better than the ERBS instrument, if the discrepancy arises from the CERES instrument, then the accepted CERES total channel response function may well be too low. Recall, however, that the comparison between theory and measurements for DCC suggests that the CERES total channel response function is too high for the far-infrared. Thus, the discrepancy in the TM suggests that the CERES total channel response function is too low in the near to mid-infrared portion of the spectrum. Thus, the results from the DCC and TM cases provide insight for two totally different spectral regions of the CERES total channel response function.

3. THREE CHANNEL INTERCOMPARISON

As previously shown, regression analysis has uncovered a highly correlated linear relationship between the CERES window channel measurements and the broadband longwave radiation for nighttime conditions involving DCC. Assuming that a reliable method is available to obtain the broadband longwave radiation for daytime conditions, the same empirical regression should also be applicable to daytime conditions involving DCC. For the daytime case, the broadband longwave radiation can be computed by subtracting the CERES shortwave measurements from the CERES total measurement.

Since our empirical regression forces the CERES window and total channel measurements to be consistent at night, we had anticipated that the broadband longwave values derived from the nighttime and daytime conditions would be consistent. We found, however, that the broadband longwave radiances derived from the daytime conditions were dependent upon the CERES shortwave measurements. The difference between the nighttime and daytime broadband longwave radiances suggested a CERES shortwave inconsistency of 0.8% compared to the CERES window channel measurement. It is not clear whether this inconsistency is with the shortwave channel or the shortwave portion of the total channel.

Another approach to analyzing the daytime measurements considers the case of all-sky data and thus provides more comprehensive results. This approach relies upon the TM, which is the average of the all-sky broadband longwave nadir data taken over the ocean in the tropics. For present purposes the tropics are defined to be $\pm 20^{o}$ latitude. Our analysis has shown that the TM is relatively constant with monthly values of the TM having a one sigma standard deviation of order 0.5%. We determine the day-night differences (DN) for the tropical mean:

$$DN = TM(day) - TM(night)$$

using the broadband longwave values derived both from the CERES window channel radiances and from differencing the CERES total and shortwave channels. The DN for the broadband longwave radiances derived from the CERES window channel is of order 1 $Wm^{-2}sr^{-1}$ and tends to be insensitive to the regression, gain error, or offset error. In contrast, the DN for the broadband longwave radiances derived from the CERES total and shortwave channels implies a CERES shortwave inconsistency of 1.2% compared to the CERES window channel measurements. Either the shortwave radiance is 1.2% low or the shortwave portion of the total channel is 1.2% high. This study using all-sky agrees with our three channel analysis of deep convective clouds. They both show about a 1% shortwave inconsistency.

4. CONCLUSIONS

A highly correlated linear relationship between the CERES window and total channel measurements exists for nighttime conditions corresponding to deep convective clouds. This relationship which was derived from measurements is consistent with theoretical line-by-line calculations to within 1-2%. We are currently trying to comprehend the source of this small discrepancy.

The broadband longwave values as derived from the CERES window channel and as derived from the CERES total and shortwave channels are consistent to about 1%. Our investigation suggests that the small remaining residual is due to our uncertainty in the spectral response functions of either the shortwave channel or the shortwave portion of the total channel.

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