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DIRECT COMPARISONS OF RADIANCES MEASURED BY INDEPENDENT CONTEMPORARY ERB INSTRUMENTS

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ABSTRACT

Comparisons of radiance measurements from overlapping independent Earth and cloud radiation budget (ERB) missions are an important contribution to the validation process of the these missions and are essential to the construction of a consistent long-term record of ERB observations. Measurements from the CERES instrument on TRMM are compared to ScaRaB on Resurs (Jan-Mar 1999) and CERES on Terra (Mar-Apr 2000).

1. INTRODUCTION

Broadband Earth radiation budget (ERB) components have been monitored from space since the late 1970's through successive independent missions. To construct a consistent long-term data set of ERB observations requires stable and reliable calibration sources as well as periods of overlap between successive missions so that the instruments can be inter-calibrated.

Narrow-field-of-view (NFOV) scanning radiometer measurements were carried out by the Earth Radiation Budget Experiment (ERBE) from 1984 to 1989, the Scanner for Radiation Budget (ScaRaB) in 1994-95 and 1998-99, and are currently being performed by the Clouds and the Earth's Radiant Energy System (CERES). These ERB instruments measure broadband radiances using a solar spectral channel (shortwave or SW: 0.2-4.0mm) and total channel (0.2-100mm). The terrestrial radiation (longwave or LW: 4.0-100mm) is derived from the total channel at night and from the difference between total and SW radiances for daytime measurements.

While ERBE NFOV instruments ceased to operate in 1989, ERBE wide-field-of-view (WFOV) nonscanning radiometers are still in operation in 2000. Green et. al. (1990) have shown that the WFOV and NFOV instruments agree to within 1% for LW and 2.5% for SW. The first ScaRaB flight model flew on the Meteor 07-3 platform and collected data from March 1994 through March 1995 (Kandel et al., 1998). Bess et al. (1997) applied the method derived by Green et al. (1990) to compare ScaRaB NFOV and ERBE WFOV data for March 1994 and found differences on the order of 1% for SW and nighttime LW and 4% for daytime LW.

The CERES protoflight model (PFM) has been gathering ERB data on the Tropical Rainfall Measuring Mission (TRMM) platform since January 1998 (Wielicki et al., 1998). It provided partial coverage of the 1997-1998 El Niño/Southern Oscillations event. Due to a failing voltage regulator, the CERES instrument stopped routine gathering of science data in September 1998. Intermittent operation occurred during 1999 for intercalibration exercises with ScaRaB and to provide ERB data during the INDian Ocean EXperiment (INDOEX). Routine operation resumed in February 2000 as soon as the CERES Flight Models 1 and 2 (FM1/FM2) started gathering science data onboard the sun-synchronous Terra platform (10.45am descending node equatorial crossing time). The second ScaRaB flight model (FM2) was launched on July 10, 1998 on-board the sun-synchronous Resurs-01/4 satellite (10.15am equatorial crossing time of the descending node). Continuous data collection occurred from November 1998 through March 1999, providing global spatial and temporal coverage of the Earth, monitoring part of the 1999 La Niña tropical anomaly. The operation overlap of, on the one hand, ScaRaB/Resurs and CERES/TRMM during Jan-Mar 1999, and, on the other hand, CERES/TRMM and CERES/Terra, provided unprecedented opportunities to carry out direct comparisons of radiances measured by independent contemporary ERB instruments.

2. RADIANCE MATCHING TECHNIQUE

Radiances measured from the CERES and ScaRaB sensors are sensitive to viewing and illumination geometries (viewing zenith angle for LW and SW and solar zenith and relative azimuth angles for SW) as well as spatial and temporal heterogeneities of the radiative fields used in the comparisons. The orbital period of the precessing TRMM spacecraft is about 10 min shorter than both sun-synchronous Resurs and Terra platforms. Every 16 hours, TRMM crosses the orbital path of either sun-synchronous platform within a few minutes of them. We consider observations at an orbital crossing to be comparable if the satellites cross each other's path within +/- 15 minutes. These conditions occur for 3 consecutive orbits every ten orbits.

At each orbital crossing between TRMM and Resurs (Terra) thousands of overlapping CERES PFM and ScaRaB FM2 (CERES FM1/FM2) footprints can be found but only about one hundred of them have matched viewing zenith angles and only close-to-nadir footprints are free of azimuth-angle dependence. Angular dependence models can be used to compare all footprints but could introduce significant errors in the comparison. The rotating azimuth capability of the CERES instruments is used to align its scanning plane to the cross-track scanning plane of the other instrument for crossings occurring in daylight. Each crossing can yield up to 51 and 102 matched SW and LW radiances, respectively.

Nadir footprint sizes of ScaRaB FM2 and CERES PFM are about 40 and 10 km, respectively, while CERES FM1/FM2 footprints are about 20km. CERES PFM footprints cannot be averaged (even using a point spread function) over the larger ScaRaB FM2 or CERES FM1/FM2 footprints because, in most cases, overlapping footprints are not viewed with the same angles. However, the effect of the discrepancy in footprint sizes can be reduced by averaging the radiance measurements on a 1-deg grid.

It can be argued that the n matched radiances observed by two instruments at an orbital crossing do not constitute independent samples. We define a new variable, $\overline{\Delta}$, the mean difference between two instruments for each orbital crossing j as $\overline{\Delta}_j = 1/n \, \Sigma_i \, \Delta_{ij}$. Adjacent orbital crossings are separated by about 3000 km so the samples of the variable $\overline{\Delta}$ are assumed to be independent.

3. RESULTS

Differences between matched radiances measured by two different instruments can originate from several sources: (1) gain and offset used to convert radiometric counts to filtered radiances and (2) assumed spectral responses used to produce unfiltered radiances. Errors in the gain and offset would affect radiances from different scene types equally, while errors in spectral corrections could affect some scenes more than others. Any error in the SW channel would not only apply to SW radiances but also to daytime LW radiances which depend on the good cross-calibration between SW and total channels. Small discrepancies in this cross-calibration were detected for the ERBE sensors onboard the NOAA-9 and NOAA-10 spacecrafts (Thomas et al., 1995). The interpretation of a calibration inconsistency between two radiometers thus needs careful attention and requires a statistically significant population made of independent samples.

Figure 1 shows a scatter plot of the matched 1-deg CERES PFM and ScaRaB FM2 shortwave radiances. The radiances have been separated by scene type. The CERES and ScaRaB SW radiances are highly correlated (R^2=0.97) and the ScaRaB-CERES difference is 1.0$Wm^{-2}sr^{-1}$, but significant scatter exists, in particular for scenes identified as mostly cloudy and overcast. The root mean square of the residuals around a linear regression line fitted on all the data (not shown) is about 8$Wm^{-2}sr^{-1}$. While the bright scene types show more scatter than the dark ones, no one particular scene type appears to have a different bias than the others, which indicates consistency between the CERES and ScaRaB unfiltering processes.

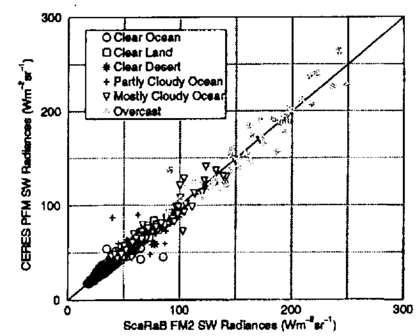

Fig. 1: Scatter plot of ScaRaB FM2 vs CERES PFM SW radiances.

The comparisons based on orbital crossing averages are given in Table 1. The mean ScaRaB-CERES difference is computed for the SW, daytime LW and nighttime LW components. Our analysis shows that the ScaRaB FM2 SW radiances are 1.1$Wm^{-2}sr^{-1}$ (1.5%) larger than the CERES PFM radiances. The uncertainty in the comparison based on a 95% confidence interval is 0.8$Wm^{-2}sr^{-1}$ (1.0%), so the ScaRaB-CERES difference is significantly different from 0. Due to our limited sample size, separation by geographical scene types or cloud cover types does not yield statistically significant results except for clear-sky ocean regions which produce results consistent with all scenes (0.9+\-0.8$Wm^{-2}sr^{-1}$). For LW radiances, the ScaRaB-CERES difference is -0.7$Wm^{-2}sr^{-1}$ (-0.8%) for daytime and 0.5$Wm^{-2}sr^{-1}$ (-0.7%) for nighttime, with a 0.1$Wm^{-2}sr^{-1}$ uncertainty in the comparison.

Table 1: Differences between collocated ScaRaB FM2 and CERES PFM radiances in units of $Wm^{-2}sr^{-1}$ (%). January to March 1999.

	Radiance	Sca-CER $\overline{\Delta}$	95% Conf. Interval	Pop. Size
SW Day	77.9	1.1 (1.5)	0.9 (1.1)	26
LW Day	85.6	-0.7 (-0.8)	0.1 (0.1)	52
LW Night	80.6	-0.5 (-0.7)	0.1 (0.1)	47

Figure 2 shows a scatter plot of the matched 1-deg CERES PFM and CERES FM1 shortwave radiances. The radiances have been separated by scene type. The CERES PFM and FM1 SW radiances are highly correlated (R^2=0.99) and the FM1-PFM difference is -0.8$Wm^{-2}sr^{-1}$, but significant scatter exists, in particular for scenes identified as mostly cloudy and overcast. The root mean square of the residuals around a linear regression line fitted on all the data (not shown) is about 6$Wm^{-2}sr^{-1}$.

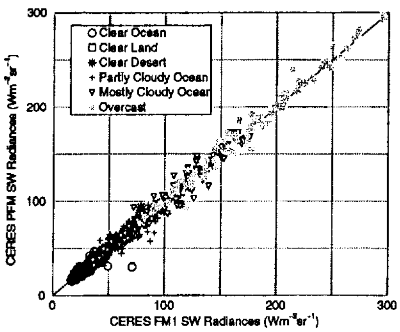

Fig. 2: Scatter plot of CERES FM1 vs CERES PFM SW radiances.

The comparisons based on orbital crossing averages are given in Table 2. The mean CERES FM1-PFM and FM2-PFM differences are computed for the SW, daytime LW and nighttime LW components. Our analysis shows that the CERES FM1 SW radiances are 0.3$Wm^{-2}sr^{-1}$ (0.4%) smaller than the PFM radiances. The uncertainty in the comparison based on a 95% confidence interval is 0.4$Wm^{-2}sr^{-1}$ (0.5%), so the difference is not significantly different from 0. Results for FM2-PFM are also shown in Table 2. Separation by geographical scene types or cloud cover types yield results consistent with all scenes. For LW radiances, the CERES FM1-PFM difference is -0.5% for daytime and 0.1% for nighttime, with a 0.1% uncertainty in the comparison. The FM2-PFM difference is -0.5%, consistent for daytime and nighttime. The IR Window radiances of FM1 are not significantly different from those of PFM, while the FM2 window radiances are 1% larger than those of PFM.

Table 2: Differences between collocated CERES FM1/FM2 and CERES PFM radiances in units of $Wm^{-2}sr^{-1}$ (%). March 2000.

	Radiance	FM1-PFM	FM2-PFM	95% C. I.	Pop. Size
SW	81.3	-0.3(-0.4)	-0.1(-0.2)	0.4	123
LW Day	86.5	-0.4 (-0.5)	-0.4 (-0.5)	0.1	146
LW Night	83.6	0.1 (0.1)	-0.3 (-0.4)	0.1	122
WN Day	7.1 /μm	0.01 (0.1)	0.07 (1.0)	0.01	64
WN Night	6.6 /μm	0.03 (0.5)	0.10 (1.5)	0.01	122

4. CONCLUSION

Comparisons of contemporary radiance measurements from two independent Earth and clouds radiation monitoring missions is an important contribution to the validation process of these missions. Our comparisons show that the difference between ScaRaB FM2 and CERES PFM SW (LW) radiances is about 1.5% (-0.5%) with a 95% confidence interval of 1% (0.1%). The differences between CERES PFM and CERES FM1/2 SW (LW) radiances are about -0.4% (-0.4%), with a confidence interval of 0.4% (0.1%). This technique allows us to develop a statistically significant population of measurements with a short overlap period between to consecutive missions.

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