P2.3 DEVELOPMENT OF CORRECTION FACTORS TO DERIVE A GLOBAL RADIATION BUDGET FROM TRIANA DATA

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1. INTRODUCTION

The Triana mission provides a unique approach to monitor the Earth's radiation budget (Valero et. al. 1999). The Triana satellite carries the Scripps National Institute of Standards and Technology Absolute Radiometer (NISTAR), which will measure global broadband shortwave (SW 0.2-5 µm) and longwave (LW 5-100 µm) radiances every few minutes. One radiometer measurement represents an entire earth view. Triana will be the first Earth-observing platform to orbit the Lagrange 1 position (L1) and will always view the sunlit side of the planet. The L1 position is 1.5 million km from Earth and orbits the sun at the same rate as the earth. This view eliminates the need for temporal corrections to derive the daytime global radiation budget, unlike the case for polar orbiters. To derive TOA global fluxes from the NISTAR data, radiances must be converted to fluxes accounting for viewed and non-viewed radiation.

The Triana nadir position can be defined in a polar coordinate system as the earth angular distance from L1 and the angle from north. Triana will view the earth entirely near the backscatter direction with scattering angles ranging from 165° to 176°. A global SW bidirectional reflectance correction factor is needed to account for the anisotropy of the reflectance field. A small sliver of the Earth's illuminated disc will not be viewed by Triana because of its Lissajous orbit about the L1 position (earth-sun line). This missing light must be taken into account. Global limb-darkening and nighttime correction factors are needed to convert LW radiance to flux because of the anisotropy of Earth emitted radiation and because Triana will not view the dark side of the globe. These global correction factors depend on the longitude, time of day, season, and orbit position. With the aid of reliable correction factors Triana should provide the most accurate global radiation budget to date, complementing higher resolution measurements like those from the Clouds and the Earth's Radiant Energy System Project (CERES).

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To derive these correction factors, it is necessary to realistically simulate the viewed scenes. Geostationary (GEO) narrowband radiances are converted to broadband fluxes and then normalized to the Earth Radiation Budget Experiment (ERBE) data. Time interpolation yields hourly regional SW and LW fluxes that are used to simulate radiances depending on the scene type and viewing and illumination angles for the region. These regional radiances are then integrated to produce a simulated single global radiance as viewed from any Triana position. Correction factors are computed and evaluated diurnally, seasonally, interannually and by orbit position. The factors are parameterized using Fourier analysis. An error analysis of the global correction factors is presented. Triana also carries the Scripps-EPIC (Earth Polychromatic Imaging Camera) for deriving cloud properties. Comparisons of cloud amount and Triana correction factors are also presented.

2. SIMULATED ERB DATASET

The Triana radiometer data are simulated using ERBE data taken between 1985 and 1988. ERBE-ERB Satellite (ERBS) instantaneous 2.5° latitude x 2.5° longitude gridded fluxes are used for non-polar regions (±60° latitude) because ERBS's coverage is limited to ± 70° latitude. ERBS samples a given location twice each day and cycles through all local hours every 36 days. The 3-hourly GEO narrowband visible (VIS) and infrared (IR) radiances from the International Satellite Cloud Climatology Project (ISCCP) are used to estimate regional fluxes between ERBS measurements. The narrowband radiances are converted to broadband fluxes empirically following the approach of Young et al. (1998). The ERBE bidirectional reflectance distribution functions (BRDF; Suttles et al. 1988) and limb-darkening models (LDM, Suttles et al. 1989) are used to correct the VIS and IR radiances, respectively, for anisotropy. The SW and LW narrowband-broadband conversion equations are similar to the formulae used by Minnis and Smith (1998). Monthly narrowband to broadband relationships for ocean, land, and snow are derived for each satellite using coincident ERBE broadband and GEO narrowband fluxes to account for calibration drift and seasonal vegetation and climate cycles. The resulting coefficients for the conversion formulae vary with season and satellite sensor.

The monthly relationships were used to compute GEO fluxes from all ISCCP radiances. Regional GEO-derived broadband fluxes were then normalized to ERBE fluxes to minimize any remaining regional biases. ERBE-like time interpolation was used to estimate fluxes at each UTC hour between the GEO observation times. The interpolation uses SW directional models (Suttles et al. 1988) to account for the solar zenith angle (SZA) dependence of albedo. Linear and half-sine wave techniques were used to interpolate LW fluxes over ocean and land, respectively.

The GEO-derived broadband fluxes were evaluated by comparing them to ERBE fluxes derived from NOAA-9 data taken between the ERBS observation times. Figure 1 shows the GOES-6 instantaneous RMS SW albedo and LW flux differences between NOAA-9 ERBE and the ERBS-GEO approach. The differences for hour zero were computed from NOAA-9 and ERBS fluxes taken sometime within the same hour interval. Thus, for the ocean region, the albedos derived from two identical sensors at different angles and slightly different times typically differ by 0.04, while their LW fluxes over a highly variable region (Fig. 1b) differ by 11 Wm^{-2}. The differences at other hours are based on the interpolation methods. The dotted line shows the differences between NOAA-9 and the values computed without using any GEO data. The dashed line corresponds to interpolation using GEO data without the normalization, while the solid line is for GEO data with normalization. These results clearly demonstrate that the normalized GEO-based fluxes are essentially as accurate as having an ERBE sensor taking measurements each hour. Incorporating GEO data sometimes doubles the monthly clear-sky LW diurnal amplitude as compared with ERBE-only time-space averaging over desert regions.

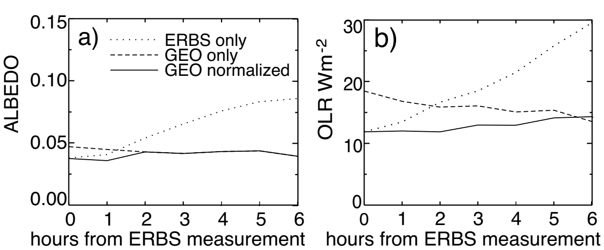

Fig. 1. RMS errors for ERBS, GEO, and GEO-normalized time-interpolated data relative to NOAA-9 ERBE instantaneous measurements as a function of the time difference between NOAA-9 and the closest ERBS measurement time for a) SW over ocean and b) LW over desert.

For polar regions, NOAA-9 (1985-1986) and NOAA-10 (1987-1988) ERBE fluxes are used without GEO data enhancement because they sample the poles up to 14 times each day. The local equator crossing times are 14:20 and 7:30 for NOAA-9 and NOAA-10, respectively. ERBE interpolation is used to create an hourly dataset.

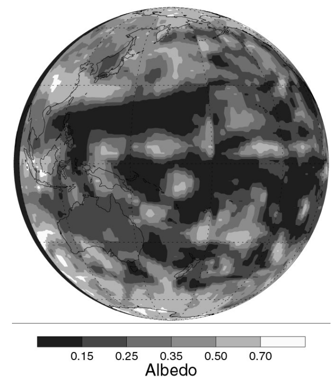

Fig. 2. Simulated Triana-view albedo for 15° East of L1 on March 21, 1986 at 00 UTC.

3. CORRECTION FACTOR RESULTS

The simulated Triana-view (TV) albedo for March 21, 1986 for Triana at 15° east of L1 is shown in Fig. 2. The left side of Fig. 2 reveals a dark sliver, the unilluminated portion of the viewed disc. The corresponding sliver of sunlit Earth not viewed by Triana behind the right side of the disc is denoted as the missing light. The TV flux is the sum of the area-weighted simulated regional fluxes that are in the Triana field of view. The TV radiance is computed in the same manner except that regional radiances are used instead of fluxes. ERBE BRDFs and LDMs are used to compute the regional radiances. The underlying surface type, latitude, and regional ISCCP cloud amounts are used to select the BRDF and LDM for a particular region for a given hour. The TV radiance is the flux times the anisotropic correction factor divided by pi. Triana global correction factors (CF) are derived at 5 angular distances from L1 (0°, 3°, 7°, 11°, 15°), every 45° in azimuth and every 15° of longitude. The daily CF variations are then averaged into monthly hourly values as shown for the example in Fig. 3. The global SW bidirectional CF is simply the Triana-view SW radiance divided by the Triana-view SW flux. The missing light CF is the total earth SW flux divided by the Triana-view SW flux. Figure 3a clearly reveals that the greatest SW bidirectional CF occurs near L1 or in direct backscatter. Figure 3b shows that the missing light CF is greater than unity to adjust for the unviewed area, which is typically brighter than average because of its very high solar zenith angle. The greatest seasonal correction occurs when Triana views the unlit pole, for example during January or July, since the sunlit pole is unviewed.

The limb-darkening CF is defined as the TV LW radiance divided by the TV LW flux divided by pi. The LW limb-darkening CF in Fig. 3c reduces the nominal radiance by up to 2.5%. The limb-darkening CF depends on water vapor burden, path length and longitude. The nighttime CF is the total Earth LW flux divided by the TV flux and is shown in Fig. 3d. The nighttime CF is usually less than unity since most scenes emit more radiation during the day than at night, especially clear-sky land. The nighttime CF is greatest when clear land

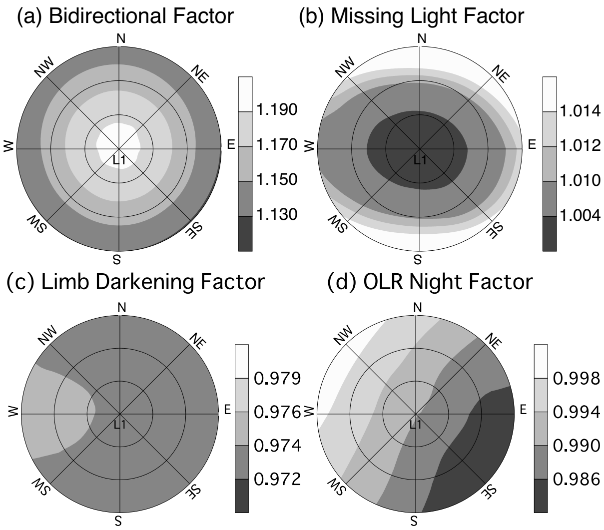

Fig. 3. Monthly mean global Triana SW and LW CF as a function of L1 offset position for March 1986 at 00 UTC.

is on one side of the earth and high clouds are on the other. The nighttime CF longitudinal variability is comparable to its seasonal variation.

The daily CF variations for a given orbit location and UTC are primarily a function of cloud variability. Triana also carries the EPIC 10-channel imager, which has a nominal 8-km nadir resolution. EPIC data will be analyzed to provide estimates of cloud amount and height. The simulated data include ISSCP daytime cloud amounts that can be linearly interpolated at night. The nighttime CF is mainly a function of cloud variability, which can be estimated from the cloud amounts. Figure 4a shows an example of a well-correlated case of TV cloud amount and the limb-darkening CF. Figure 4b shows the relationship between the nighttime CF and the cloud factor, which is the ratio of the instantaneous global cloud amount divided by the TV cloud amount. Unfortunately, the relationship between cloud amount and the daily SW CF is less obvious. However more sophisticated determinations of the SW bidirectional CF can be developed using EPIC high-resolution data to determine regional cloud amounts and estimate the TV radiance in the same way used to develop the simulated dataset. An angularly dependent narrow-to-broadband conversion model (e.g., Chakrapani et al. 2002) tailored

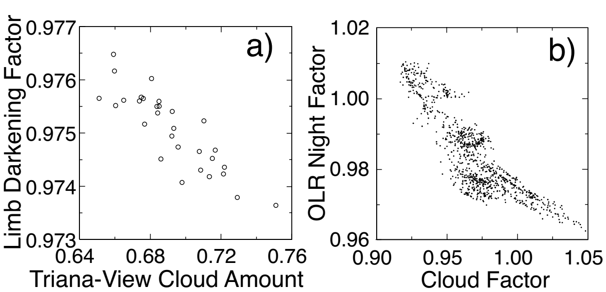

Fig. 4. a) Daily variation of Triana limb-darkening CF as a function of cloud amount for TV 7° north of L1, March 1986, 22 UTC; b) Daily variation of TV nighttime cloud amount for all Triana positions for March 1986, 23 UTC.

to the viewing conditions for different scene types cloud be used to convert EPIC radiances to SW radiances.

A bias in the backscatter part of the model could have serious consequences. The ERBE bidirectional model (Suttles et. al. 1988) contains standard deviations for each angular bin. For example, ocean standard deviations vary from 20% for clear to 35% for overcast at a cosine solar zenith angle of 0.95, a view angle of 21° and azimuth angle of 175.5°. In order to assess this uncertainty, each regional Triana radiance is converted to a flux using a bidirectional CF which is determined at random and confined within the given standard deviation. The simulated and random error fluxes are averaged over all hours and days for each orbital position. An instantaneous RMS error is computed using all 744 images during the month for all 40 orbit locations. The instantaneous error in global allbedo due to uncertainties in the ERBE model is 0.00123 or 0.42%. The uncertainty is the same regardless of the L1 position. The same procedure was followed for the limb-darkening error assessment. The limb-darkening correction error is 0.21% or 0.51 Wm^{-2}. The largest ERBE LW bin standard deviations are for overcast conditions (~25%), whereas clear ocean is at 5% (Suttles et. al. 1989). These errors are quite small and unprecedented. The large reduction in the bidirectional error is the result of Triana viewing so many different scene types at a single time. The statistical variation in the correction factors is almost captured in its entirety when the entire Earth disc is viewed. When computing daily or monthly averages, the anisotropic errors become negligible.

4. CORRECTION FACTOR PREDICTION MODEL

For climate monitoring, Triana-derived fluxes will be averaged into monthly products similar to ERBE and CERES. A simple monthly CF model based on historical climatology can be built using 3 years of simulated data (1985-1987). Table 1 shows the mean CF values based on the 3 years of simulated data. The nighttime CF increases as the satellite moves further from L1 because more unlit portions of the disc are in the Triana view. The individual hourly CF values will be used to derive the global fluxes from the 1988 ERBE radiance data and then compared with 1988 data to determine the error in this approach.

Table 1. Annual Triana correction factors as a function of distance from L1 based on 1985-1987 simulated data.

Triana Distance from L1	Bidir-ectional Factor	Missing Light Factor	Limb Dark Factor	OLR NIGHT Factor
0°	1.1704	1.0001	0.9742	0.9812
3°	1.1681	1.0008	0.9742	0.9812
7°	1.1547	1.0032	0.9742	0.9813
11°	1.1357	1.0069	0.9741	0.9816
15°	1.1166	1.0115	0.9740	0.9821

A more robust approach would be to evaluate the CF cycles using Fourier analysis in order to isolate dataset artifacts and long-term trends. Hopefully this approach is independent of the dataset. Fourier analysis was performed on 4 years of monthly hourly nighttime CF for each orbit location. The interannual trend is removed by a 2nd order polynomial fit. Figure 5a shows the results for 15°N of L1 with the seasonal cycle overlaid. Fourier analysis reveals a strong seasonal, diurnal and seasonally modified diurnal cycles. The coefficients for these cycles are derived by least squares regression of the 3-year dataset. The resultant coefficients were used to predict the CF and are compared against the simulated data for 1988 (see Fig. 5b). Preliminary results indicate that the model is capable of resolving the nighttime CF.

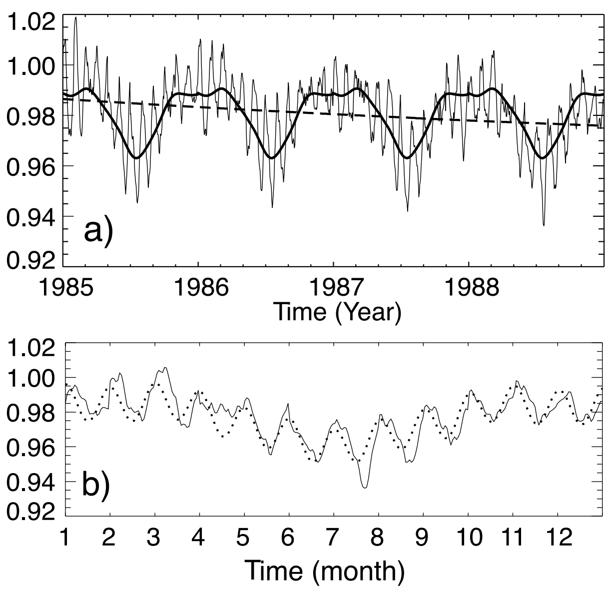

Fig. 5. Time series analysis of simulated monthly hourly OLR-night CF at 15° north of L1 for: a) the simulated time series (solid line), seasonal cycle (thick solid line) and inter-annual trend (dashed line), b) Predicted (dashed line) and simulated 1988 OLR-night CF (solid line).

5. CONCLUSIONS

Since Triana continually looks at the earth's sunlit side, it is a unique platform for climate monitoring and provides complete daytime synoptic views. Triana full-disc radiances are converted to global fluxes using four correction factors. The largest correction factor is the SW bidirectional CF which also has the greatest potential for error when derived from historical datasets. This error is rendered to a negligible value because the disc scene contains nearly the entire set of statistics used to develop bidirectional reflectances models for a limited set of angles. The two LW CF are virtually independent of orbit distance. Diurnal and seasonal variations are significant for all CF. Daily LW CF variations are tied to cloud variability, which can be obtained from the Triana imager. The correction factors are sensitive to the ERBE angular distribution models that are applied to the simulated dataset. Using a CERES based temporally averaged dataset, which uses GEO data, would increase the confidence in the CF, since CERES uses nearly 600 models in the SW alone. Any uncertainty in the current approach can be reduced by incorporating products derived from the Triana EPIC imager.

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