CERES TRMM-PFM-VIRS Edition1 SSF Clear-Sky TOA Fluxes - Accuracy and Validation

CERES shortwave (SW), longwave (LW), and window (WN) channel fluxes are derived from empirical Angular Distribution Models (ADMs) that convert a measured radiance in a given sun-earth-satellite viewing configuration to a top-of-atmosphere (TOA) flux. In the Earth Radiation Budget Experiment (ERBE), as well as the CERES ERBE-Like product, a set of 12 ADMs were used. These models relied on scene identification from the Maximum Likelihood Estimation technique (Wielicki and Green, 1989). Since ADMs are highly sensitive to the physical properties of the observed scene, the strategy for the CERES SSF product is to construct new ADMs that take advantage of improved scene identification from high-resolution, multi-spectral imager measurements. However, Loeb et al. (2000) have demonstrated that errors in scene identification (e.g. cloud fraction, cloud optical depth, cloud phase) can lead to large, systematic biases in TOA flux estimates. That study, together with a second study by Loeb et al. (1999), stressed the importance of using the same scene identification scheme in both development and application of ADMs for determining TOA fluxes. Unfortunately, CERES SSF Edition1 processing is not expected to be completed until February 2001. Since approximately 6 months are needed to develop, implement, and validate ADMs from the new SSF Edition1 cloud properties, a complete, up-to-date set of CERES ADMs is scheduled to be delivered approximately 6 months after the completion of the SSF Edition1 processing. Shortly thereafter, the CERES-TRMM SSF Edition2 product will be produced with updated cloud properties and CERES fluxes inferred from ADMs based on CERES SSF Edition1 scene identification.

In the meantime, CERES SSF Edition1 does include preliminary flux estimates for clear-sky conditions only. CERES clear-sky footprints are identified using the CERES VIRS cloud mask over ocean, land and desert. Three clear-sky ADM classes are defined for these surfaces. Owing to the lack of CERES-TRMM measurements over snow, the ERBE clear snow ADM is used to determine fluxes under those conditions. To estimate the uncertainties in SW and LW fluxes from these ADMs, a second, more complete set of ADMs based on parameters from an early version of the SSF product was considered. 12 clear-sky ocean SW ADMs stratified by wind speed and percentiles of the CERES SW reflectance in each angular bin outside of the sunglint region were constructed. The SW reflectance percentile bins are directly related to the aerosol optical depth of the scene. Over land and desert, clear-sky SW ADMs stratified by the International Geosphere Biosphere Programme (IGBP) classification scheme were developed. To estimate uncertainties in LW fluxes, a set of LW clear-sky ADMs stratified by 4 intervals of precipitable water were constructed. Results from these comparisons can be summarized as follows:

- When the entire population of clear-sky ocean scenes are considered, the mean SW flux remains unbiased even if only one ADM is used to estimate SW fluxes. However, when the clear-sky ocean population is stratified by wind speed and aerosol optical depth, SW fluxes under conditions of low wind speed and low aerosol optical depth are underestimated by approximately 6% (corresponding to a 2.0-2.5 W m^{-2} equivalent diurnal flux bias). Conversely, at high wind speeds and high aerosol optical depths, fluxes based on a single clear-sky ADM are overestimated by approximately 4% (or a 1.5-2.0 W m^{-2} flux bias).

- In clear regions over land and desert, bias errors from the use of a single "land" and a single "desert" ADM are shown in Table 1 for each IGBP surface type. Flux bias errors (equivalent diurnal average) generally remain well below 2 W m^{-2} in all cases. Larger flux bias errors are expected, however, in conditions of heavy aerosol loading (e.g. dust storms, smoke).

- Uncertainties in LW fluxes due to the use of a single clear-sky ocean ADM are found to show a slight systematic trend with precipitable water (w). When only viewing zenith angles < 45 deg are considered, fluxes under dry conditions (w < 2 cm) are underestimated by approximately 0.2 W m^{-2}. For w > 4 cm, the flux error can reach 1 W m^{-2}. Conversely, when viewing zenith angles from nadir to 70 deg are considered, flux bias errors remain < 0.3 W m^{-2} for all w.

While it would have been possible prior to the CERES-TRMM SSF Edition1 release to have used a fairly mature version of the CERES VIRS cloud mask to develop a set of ADMs stratified by cloud cover only (similar to what was done in ERBE), validation studies indicated that ignoring the ADM dependence on cloud optical depth would have led to TOA flux errors exceeding those for ERBE. The reason is due to the dramatic difference in scene identification between the VIRS cloud mask and the ERBE scene identification scheme. ERBE scene identification uses the Maximum Likelihood Estimation (MLE) technique (Wielicki and Green, 1989) to classify scenes into 4 cloud-cover classes (clear, partly cloudy, mostly cloudy and overcast) based on broadband SW and LW measurements. In contrast, CERES SSF uses VIRS high-resolution, multi-spectral imager measurements to characterize the scene over a CERES footprint. Table 2 shows typical differences between the VIRS cloud mask and MLE-based scene type frequencies of occurrence over ocean when both methodologies are applied to one day (January 21, 1998) of coincident CERES and VIRS-TRMM measurements. The largest discrepancy occurs for overcast scenes: according to the VIRS cloud mask, daytime (nighttime) overcast scenes occur 41% (37%) of the time, compared to only 13% (9%) from the ERBE MLE technique. This difference is compensated by a larger frequency of occurrence of clear, partly cloudy and mostly cloudy scenes for the MLE technique. The reason for the huge difference in overcast frequency of occurrence is because the VIRS cloud mask is far more sensitive to extensive, thin cirrus layers than the ERBE MLE technique. The latter tends to classify scenes that are cold and bright as overcast, while the population of overcast scenes from the VIRS cloud mask has a much wider range of optical thicknesses. When the VIRS cloud mask is used to define only one overcast ADM scene class, and the influence of cloud optical depth and cloud phase on anisotropy are ignored, average SW fluxes from clouds with optical depths < 5 are underestimated by 25%-30%, while average fluxes for clouds with optical depths > 5 are overestimated by 3-5% for CERES viewing zenith angles < 45 deg. For ERBE, these biases are reduced because the overcast population consists mainly of thick, cold, and bright clouds, which have a smaller range of anisotropy. Another important factor that reduces ERBE flux errors is the compensation of errors that results when fluxes inferred from viewing zenith angles ranging from nadir to 70 deg are averaged together (Suttles et al., 1992). Such a compensation of errors is not always realized for the CERES-TRMM SSF product because this product considers only footprints that lie within the VIRS swath. When CERES is scanning in the across-track direction, only footprints with viewing zenith angles between nadir and approximately 45 deg are considered. The full range of CERES viewing zenith angles is retained, however, when CERES is in the Rotating Azimuth Plane (RAP) and along-track scan modes.

In summary, TOA fluxes on CERES-TRMM SSF Edition1 are available for clear scenes only, and are based on a preliminary set of ADMs. The full set of CERES-TRMM TOA fluxes under all sky conditions will be available on CERES-TRMM SSF Edition2. The ADMs used to determine fluxes for the CERES SSF Edition2 product will be based on cloud properties from the current Edition1 version of the SSF.

Table 1: Spherical albedo, flux bias (equivalent diurnal average) and relative flux bias for each IGBP type.

IGBP Type	Spherical Albedo (%)	Flux Bias (W/m^2)	Relative Flux Bias (%)
1. Evergreen Needleleaf Forest	16.8	-0.89	-1.6
2. Evergreen Broadleaf Forest	16.0	-1.36	-2.5
3. Deciduous Needleleaf Forest	-	-	-
4. Deciduous Broadleaf Forest	16.8	-0.68	-1.2
5. Mixed Forest	15.3	-1.08	-2.1
6. Closed Shrublands	16.8	1.64	2.9
7. Open Shrublands	21.8	-0.37	-0.5
8. Woody Savannas	16.9	-0.93	-1.6
9. Savannas	18.5	0.56	0.9
10. Grasslands	19.9	1.52	2.2
11. Permanent Wetlands	-	-	-
12. Croplands	18.6	-0.70	-1.1
13. Urban and Built-up	-	-	-
14. Cropland Mosaics	17.5	-0.15	-0.3
15. Snow and Ice (permanent)	-	-	-
16. Bare Soil and Rocks	29.3	0.80	0.8
17. Water Bodies	(See clear ocean results)		
18. Tundra	-	-	-
19. Fresh Snow	-	-	-
20. Sea Ice	-	-	-

Table 2: Scene type frequency of occurrence for clear, partly cloudy, mostly cloudy and overcast scenes over ocean as determined by the MLE technique and the VIRS cloud mask for daytime and nighttime conditions.

Scene Type Frequency of Occurrence (%)				
Scene Type	Daytime		Nighttime	
	MLE	Imager	MLE	Imager
Clear	36	26	25	29
Partly Cloudy	28	18	46	17
Mostly Cloudy	23	15	20	17
Overcast	13	41	9	37

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