CERES TRMM Beta2 SSF
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. In Beta2, a preliminary set of SW, LW and WN ADMs stratified by imager-derived cloud properties are used to estimate TOA fluxes. The cloud properties are from the TRMM SSF Edition1 product. While these ADMs are a significant improvement over the ADMs used in ERBE and ERBE-Like products, they are preliminary and will be improved upon in Edition2. The Edition2 ADMs will use updated (Edition2) cloud products.

The main strength of the Beta2_TRMM ADMs lies in the improved scene identification from VIRS. This allows for a better discrimination between cloud and clear fields of view, which is of paramount importance for aerosol and cloud forcing studies. Also, since cloud properties based on VIRS radiances are available over each CERES footprint, this means that ADM scene types can be defined according to parameters that have the greatest influence on the anisotropy of the scene. These improvements translate to a reduction in flux errors. A detailed description of the ADM scene types is provided in the 23rd CERES Science Team Meeting Presentation (January 2001) by Loeb for SW fluxes (PDF) and Manalo-Smith for LW and WN fluxes (PDF). Briefly, the Beta2_TRMM ADMs are divided into broad classes of clear and cloud scenes over ocean, land, desert and snow. Each of these is further stratified by several parameters that influence anisotropy. Unlike ERBE scene types, the Beta2_TRMM ADM SW and LW classification schemes are independent of one another. For example, SW cloud ADMs are stratified by cloud phase, cloud fraction and cloud optical depth, whereas LW cloud ADMs use retrievals of IR emissivity, precipitable water, and surface-cloud temperature difference. Other important differences include the manner in which land and desert are categorized in the SW. As shown in the above presentation, land is separated into a moderate-to-high tree/shrub coverage class (i.e. mainly forests) and a low-to-moderate tree/shrub coverage class (i.e. mainly grasslands), whereas desert is stratified by "dark" desert and "bright" desert. Since the sampling over snow from TRMM is insufficient to develop ADMs, snow ADMs are still based on those used in ERBE. These will be replaced by a set of theoretical snow ADMs in Edition 2 (for Terra new empirical snow ADMs will be developed).

The main weakness of the Beta2_TRMM ADMs is missing IR emissivity retrievals during the daytime (~15% of the time) and missing IR emissivity at night. These were inadvertently left off of the SSF when Edition 1 SSFs were created. This omission will be corrected in the SSF Edition 2 product. In the meantime, when a footprint's cloud IR emissivity is unavailable, fluxes based on a simpler set of ADMs (VIRS12B) are used. The VIRS12B ADMs assume a scene identification that is similar to ERBE (i.e. clear, partly cloudy, mostly cloudy and overcast) but is based on the imager cloud mask rather than the ERBE MLE technique.

During the 24th CERES Science Team Meeting (May 2001) Loeb et al. provided a detailed analysis of the errors for fluxes based on Beta2_TRMM ADMs, VIRS12B ADMS and ERBE ADMs (PDF) (from the CERES ES-8 product). That presentation is attached here for reference. Results from that study can be summarized as follows:

- A new clear ocean SW ADM that attempts to account for variations in aerosol optical depth and wind speed was introduced. Fluxes based on the new ADMs tend to be larger at low aerosol optical depths compared to Edition 1, and smaller when aerosol optical depth is high. Recent tests based on alongtrack measurements indicate that instantaneous fluxes based on Beta2_TRMM ADMs are self-consistent to within 2% compared to 9% for ERBE-Like (Loeb and Kato, 2001).

- SW fluxes from Beta2_TRMM ADMs tend to be lower than Edition 1 over land and desert. The difference is more pronounced over brighter surfaces (e.g. bright desert). This trend is likely due to improvements in the Beta2_TRMM ADM definition of desert. Use of separate dark and bright desert ADMs means a more isotropic bright desert ADM in Beta2, resulting in lower average fluxes.

- Cloud optical depths used to classify ADM scene types are different from those that appear on the SSF. The new optical depths adjust the SSF optical depths to force the ensemble cloud optical depth distributions to be self-consistent in all viewing geometries. The mean adjusted cloud optical depth remains invariant with viewing zenith angle while the SSF cloud optical depth systematically decreases between nadir and oblique imager viewing zenith angles (for VIRS the maximum viewing zenith angle is ~48°).

- All-sky albedos based on Beta2_TRMM ADMs systematically increase by 5-7% between nadir and the most oblique VIRS viewing zenith angle. This trend is similar to that found in VIRS12B ADMs (which only use cloud fraction retrievals for scene identification). The albedo bias from the ERBE-like product is twice as large as that for Beta2. The dependence in the Beta2 and VIRS12B ADM albedos with viewing zenith angle is very similar to that for cloud fraction. The all-sky mean cloud fraction increases by ~10% between nadir and 48° viewing zenith angle. The increased cloud fraction at larger viewing zenith angles is most likely due to the influence of cloud geometry (i.e. cloud sides). Efforts are under way to reduce these albedo biases for Edition 2.

- The LW flux dependence on viewing zenith angle is much smaller than for SW. The LW flux dependence remains less than 2%.

- Mean Beta2 all-sky SW fluxes stratified by latitude and solar zenith angle are generally within 1% of those inferred by direct integration of the mean radiances. Equivalent (spherical albedo) flux biases remain within 1 W m^{-2}, both when CERES viewing zenith angle ranges are restricted to 0°-50° and 0°-70°. In contrast, ERBE-like fluxes show a larger deviation from direct integration fluxes and the differences show a dependence on solar zenith angle. Equivalent (spherical albedo) flux biases remain within 1 W m^{-2} only when the viewing zenith angle range is between 0°-70° - the bias increases by a factor of 4 when the CERES viewing zenith angle range is restricted to 0°-50°.

- Albedos from deep convective clouds based on Beta2_TRMM ADMs were compared with those using ADMs from Hu et al. (2001). Albedo differences remained < 0.5%.
- Regional fluxes biases using Beta2_TRMM ADMs over the warm pool and over regions of stratiform cloud are a factor of 2 smaller than ERBE-Like fluxes for the same regions.
- Regional LW and WN flux biases over 10°x10° deg regions were generally < 0.5 W m^{-2}. RMS errors were typically 1 W m^{-2} for LW fluxes and 0.5 W m^{-2} for WN fluxes. By comparison, ES8 LW flux biases and RMS values are more than a factor of 3 larger.
- Errors in mean fluxes for clear scenes are shown in Table 1. Table 2 demonstrates the rather large differences in scene identification between the VIRS cloud mask and ERBE MLE.
- A summary of errors in all-sky equivalent (spherical albedo) SW flux bias is provided in Table 3. Tables 4 and 5 provides LW and WN flux results, respectively.

In summary, Beta2 TOA SW, LW and WN fluxes represent a significant improvement over ERBE-Like fluxes. Efforts are underway to further improve these ADMs for Edition2.

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	Scene Type Frequency of Occurrence (%)

	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

Table 3: All-sky equivalent (spherical albedo) flux bias (W m^{-2})

	ES8		Edition 1		Edition2_Beta	
	θ < 50	θ < 70	θ < 50	θ < 70	θ < 50	θ < 70
All Tropics	-2.6	-0.15	-1.2	-0.67	-0.49	-0.13
Land+Desert	-2.0	-0.56	0.83	-0.14	-0.64	-0.40

Table 4: All-sky LW flux bias (W m^{-2})

	Edition1		Edition2_Beta	
Season	**Bias**	**RMS**	**Bias**	**RMS**
Jan-Mar	0.09	1.2	0.6	1.15
Jun-Aug	0.04	1.2	0.43	0.74

Table 5: All-sky WN flux bias (W m^{-2})

	Edition1		Edition2_Beta	
Season	**Bias**	**RMS**	**Bias**	**RMS**
Jan-Mar	0.05	0.58	0.31	0.55
Jun-Aug	0.03	0.56	0.25	0.39

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