Improvements to Broadband Shortwave and Longwave Top of Atmosphere Fluxes from Geostationary Satellites

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Introduction

- Satellite monitoring of top-of-atmosphere (TOA) broadband (BB) shortwave (SW) and longwave (LW) fluxes is important for understanding cloud-radiative interactions, evaluating climate change and for other applications.
- Geostationary satellites (GEO) are advantageous since their positioning allows them to observe the full diurnal cycle across most of the globe with high temporal resolution. Most GEO's, however, are only equipped with narrowband (NB) instruments.
- Narrowband-to-broadband (NB-BB) flux conversions are employed operationally within the NASA Langley SatCORPS (Satellite Cloud Observations and Radiative Property retrieval System) in order to estimate BB radiation parameters at GEO resolutions, but have limitations.

Objectives

- Improve SatCORPS NB-BB formulations by incorporating additional NB spectral information, and by better accounting for dependencies on view angle, water vapor loading, scene type and seasonality
- Apply initially to GOES-13 covering ARM (Atmospheric Radiation Measurement) Mobile Facility GO-AMAZON (Green Ocean-AMAZON) domain
- Assess accuracy of improvements and potential for application to other geostationary satellites.

LW Data & Methodology

"Operational" NB-BB Flux Fit:

- Input Data for Fit:
  - CERES instantaneous Terra FM1 and Aqua FM4 CERES ERBElike ES8 BB fluxes M_{LW}
  - GOES-8 matched resolution avg 10.8-µm fluxes M_{nb}
- LW fits derived separately for land and ocean, but include both day/night
- Derived over Florida Domain, Summer 2002
- Fit matched data to:

$$M_{LW} = A_0 + A_1 {}^* M_{nb} + A_2 {}^* M_{nb}^2 + A_3 {}^* M_{nb} {}^* \ln(\text{colRH}), \qquad (1)$$

Where M_{LW} = *LW flux or OLR; colRH= column-weighted RH from model, e.g. RUC*

"Updated" NB-BB Flux Fits:

- Input Data for Fit:
  - global, month-specific CERES Aqua FM3 Edition 4 Single Scanner Footprint (SSF)
  - collocated CERES BB LW fluxes M_{LW} ; MODIS NB 11µm R_{11}, 6.7 µm R_{67} radiances
- LW fits derived in similar fashion to CERES SYN1Deg product LW NB-BB
  - Day vs night
  - 7 scene types (Ocean, Snow, Forest, Grass, Bright Desert, Dark Desert)
  - Fits binned by Viewing Zenith Angle (VZA), Total Precipitable Water (PW), and R_{11}
    - 4 PW bins (cm): 0.0,1.0,3.0,5.0,10.0 (from CERES MOA product)
    - 6 Radiance M_{11} bins ($Wm^{-2}st^{-1}\mu m^{-1}$): 0.0,2.0,4.0,6.0,8.0,10.0,12.0
    - VZA (°): 0,2,4,6,8,10,12,14,16,18,20,22,24,26,28,30,32,34,36,38,40,42,44,46,48,50,52,54,56,58,60,70
- Fit matched data to:

$$M_{LW} = B_0 + B_1 {}^* R_{11} + B_2 {}^* R_{67} \qquad (2)$$

- GOES-13 10.8, 6.7µm brightness temperatures calibrated to MODIS
- MODIS-CERES fits applied to GOES-13 R_{11},R_{67} yield intermediate fluxes M_{LWI}
  - **Applied over GO-AMAZON domain (3°N- 10°S, 50°W – 70°W)**
  - **GO-AMAZON IOP1 & 2 (Feb-Mar14 Wet Season, Sep-Oct 14 Dry Season)**
- GOES-13 intermediate fluxes M_{LWI} normalized to CERES Aqua
  - match 1° GOES-13 vs CERES Aqua Edition 3 Surface Fluxes and Clouds (SFC) gridded 1° LW fluxes within localized region during month
  - determine linear correction, apply to each 1° gridbox to yield final "Updated" LW fluxes

Validate by comparing results with CERES SFC Terra, and CERES Edition 4 SYN1deg gridded hourly product

AQUA MODIS-CERES LW NB-BB Flux Fits and Normalization

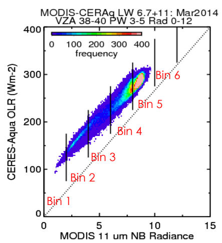

Figure 1. Global monthly March 2014 Ocean Day MODIS R_{11} plotted against collocated Aqua CERES BBLW fluxes. Plot represents PW 3-5cm and 38°-40° VZA bin; vertical lines depict breakdown of R_{11} bins. MODIS R_{11} regressions with R_{67} against Aqua CERES BB fluxes yield coefficients (B0-B2), bias, and RMS as listed in Table 1. Similar regressions performed for all scene types/bins with valid data, during the IOPs' 4 months (not shown). Coefficients applied to MODIS-calibrated GOES-13 R_{11}, R_{67} per Eq (2) yield "Intermediate" LW fluxes M_{LWI}.

Table 1

	B0	B1	B2	BIAS (Wm^{-2})	RMS (Wm^{-2})
Bin1	75.06	10.53	73.26	4.8e-5	3.54
Bin2	73.99	14.32	59.36	-7.3e-5	4.44
Bin3	80.69	15.57	46.45	1.1e-4	6.61
Bin4	79.56	18.33	33.36	5.4e-4	6.41
Bin5	86.30	19.00	23.75	-6.1e-4	3.25
Bin6	N/A	N/A	N/A	N/A	N/A

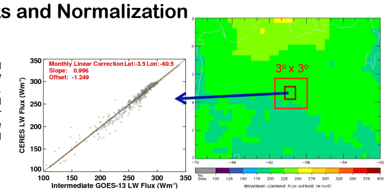

Figure 2. GOES-13 LW fluxes M_{LWI} are then normalized to CERES. This step accounts for remaining satellite- and domain-specific differences from the globally derived MODIS-CERES LW NB-BB fits, improving the local bias. A linear correction is determined for each 1° gridbox in the GO-AMAZON domain, from monthly matched data within the surrounding 3° x 3° region.

Validation with CERES: GOES-13 Derived LW fluxes vs Aqua and Terra

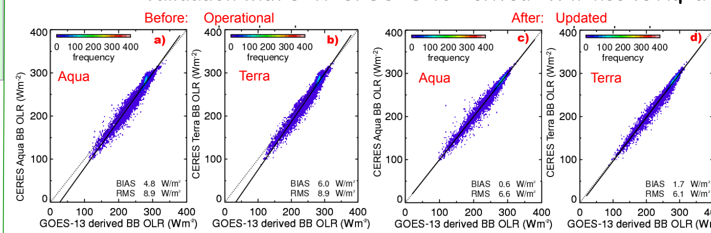

Table 2

		Aqua Before W/m² (%)	Aqua After W/m² (%)	Terra Before W/m² (%)	Terra After W/m² (%)
Feb14	Bias	3.5 (1.7%)	-0.8 (-0.4%)	4.2 (2.0%)	0.4 (0.2%)
	RMS	8.5 (4.1%)	6.8 (3.2%)	8.5 (4.0%)	6.4 (3.0%)
Mar14	Bias	5.3 (2.5%)	-0.5 (-0.2%)	6.3 (3.0%)	0.7 (0.3%)
	RMS	8.9 (4.2%)	6.9 (3.3%)	8.8 (4.2%)	6.7 (3.2%)
Sep14	Bias	4.8 (1.9%)	0.6 (0.2%)	6.0 (2.3%)	1.7 (0.7%)
	RMS	8.9 (3.5%)	6.6 (2.6%)	8.9 (3.5%)	6.1 (2.4%)
Oct14	Bias	6.6 (2.9%)	0.0 (0.0%)	8.7 (3.8%)	1.9 (0.8%)
	RMS	9.0 (4.0%)	7.1 (3.1%)	8.8 (3.8%)	6.4 (2.8%)

Figure 3. Sep2014 GOES-13 derived LW fluxes from operational (a, b) and updated (c, d) methods compared to gridded CERES Edition 3 SFC Aqua and Terra BB fluxes. Agreement with CERES improves greatly using the updated NB-BB methodology. Compared to Aqua, LW Bias improved from 4.8 W/m² to 0.6 W/m². Terra comparisons yield a more independent assessment of the Aqua-based fits, with updated method bias decreasing to 1.7 W/m². Largest change in bias is seen in lower portion of the range, which turns colder in updated derived LW fluxes; this is consistent with the other months (not shown). Operational and updated bias, RMS are summarized in Table 2; all months' bias/RMS improved by using the updated method.

Results

March 20, 2014 1115 UTC GOES-derived BBLW Fluxes

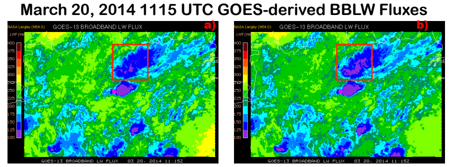

Figure 4. March 20 2014 1115 UTC GOES-13-derived LW fluxes a) Operational b) Updated. Red square highlights a convective area's OLR decrease, consistent with Fig.3 trend in lower range.

Sep14 Monthly Average GOES-derived BBLW Fluxes

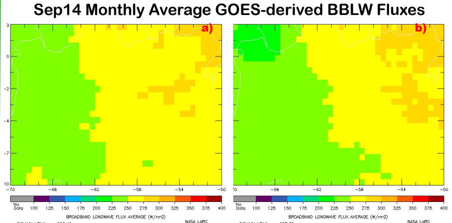

Figure 5. Sep 2014 GO-AMAZON domain monthly averaged GOES-13-derived LW fluxes a) Operational b) Updated. Upper left of the domain shows decreased OLR, while portions at right increase slightly, consistent with corrections seen in the higher and lower ranges of Fig. 3. The updated domain mean decreases 4.1 W/m², consistent with the decrease seen in Fig. 3.

Assessment vs CERES Edition 4 SYN1Deg

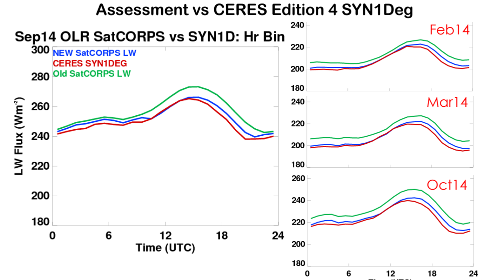

Figure 6. Sep14 GOES-13 vs CERES SYN1deg hourly averaged LW fluxes. Updated GOES-13 LW fluxes denoted in blue, operational in green, CERES red. Updated GOES-13 LW fluxes match the CERES trend more closely. Agreement is best in the morning/nighttime, with more divergence in the afternoon/evening. Similar trends seen for all months. This may be due, in part, to angular differences between GOES & Aqua/Terra.

More Information and Data Available:
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New SW NB-BB Procedure (in progress)

Operational method (data and domain same as in LW Method):

$$A_{SW} = a_0 + a_1 {}^* A_{nb} + a_2 {}^* A_{nb}^2 + a_3 {}^* \ln(1/\mu_o) \qquad (3)$$

Where A_{SW} = *BB SW albedo;* A_{nb} = *SW 0.65 µm albedo;* μ_o = *cos(SZA)*

Goal: Update SW NB-BB methodology to more closely match CERES Edition 5 GEO NB-BB method (currently in development). Derive NB-BB radiance fits using theoretical modeled BB radiance based on numerous cloud, scene, and angular parameters, matched to particular GEO visible channel spectral response functions.

- **GEO can't use SW MODIS-CERES NB-BB**
  - Terra/Aqua obs do not cover all angle (SZA, RAZ) bins GEOs observe
- Theoretical BB Radiative Transfer (RT) Modeled Dataset (MD) in development
  - uses code based on DISORT
- RTMD provides theoretical SW BB radiance RT_{SW} similar to that of CERES, based on full range of binned GEO-required angles/ observation types:
  - Angles (*a*) : SZA (6 bins), VZA (23 bins), RAZ (19 bins)
  - Cloud Properties (*c*): phase, top/base heights, optical depth (τ), eff. Diam.
  - Atmospheric Profiles (*p*) (based on varying PW), wind speed
  - Aerosol optical depths (*o*)
  - Surface scene type: 16 IGBP Scene Types (*s*)
- GEO satellite-specific NB radiances are convolved from BB radiances using visible channel spectral response functions & regressed linearly with RT_{SW} *(function of* τ*)*,per all angle/obs type bins
- determine LUT of binned NB-BB fit coefficients (slope/offset)

Based on theoretical LUT, using angle/observation bins, GEO observed NB radiances $R_{0.65}$ ***can be converted to SW BB radiance:***

$$R_{SW} = S_{acpos} {}^* R_{0.65} + O_{acpos} \qquad (4)$$

Where $R_{0.65}$= *GEO 0.65 µm radiance;* O_{acpos}=*Offset (per bin);* S_{acpos}=*Slope (per bin)*

TRMM ADM's can then be used to invert R_{SW} ***to SW BB Flux.***

Summary

- A new LW NB-BB procedure has been developed using MODIS 6.7/11µm and CERES BB fluxes which better accounts for dependencies on water vapor, scene type, view angle, time of day, and seasonality
- RMS errors for LW MODIS-CERES NB-BB fits:
  - Daytime LW: Land 0.5%-6.3%; Ocean 0.6%-4.4%; Snow 0.8%-6.4%
  - Nighttime LW: Land 0.3%-5.4%; Ocean 0.4%-3.7%; Snow 0.7%-4.2%
- Validation with CERES Terra and Aqua shows decreased LW Bias and RMS over the GO-AMAZON domain/IOPs, when applying updated fits and normalization

Future Work

- Apply to other geostationary satellites and domains
- More validation with CERES and comparisons with Fu-Liou modeled fluxes
- New Procedure for SW NB-BB in development that adapts CERES Edition 5 NB-BB methodology:
  - Incorporates theoretical RT modeled BB SW radiance, since angle bins (SZA, RAZ) from Aqua/Terra are incomplete for SW GEO applications
  - Initial evaluation will utilize GOES-13 GO-AMAZON dataset validated with CERES and Fu-Liou RT modeled fluxes