Improving the CERES Derivation of SW TOA Broadband Fluxes from GEO Narrowband Radiances with the Anticipation of the Next Generation GEO Sensors

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IMPROVING THE CERES DERIVATION OF BROADBAND FLUXES FROM GEO NARROWBAND RADIANCES WITH THE ANTICIPATION OF THE NEXT GENERATION GEO SENSORS

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1 INTRODUCTION

The Clouds and the Earth's Radiant Energy System (CERES) project provides the climate community with three types of monthly averaged data sets. These data are as follows. (1) The CERES EBAF flux product are generated from monthly and climatological averages of TOA and surface clear-sky (spatially complete) fluxes, all-sky fluxes, and cloud radiative effect (CRE), where the TOA net flux is constrained to the ocean heat storage term (0.58Wm^{-2}). These fluxes are appropriate for climate model comparisons, since the net balance is not tied to the CERES calibration and surface fluxes are consistent with the TOA fluxes. These fluxes are considered diurnally complete. (2) Secondly, the SSF1deg products are based on the CERES single satellite monthly and daily averaged TOA fluxes and MODIS cloud properties using constant meteorology at the time of the CERES measurement. These fluxes are not diurnally complete and should only be used when comparing to other Terra or Aqua datasets. (3) Lastly, the CERES SYN1deg product are derived from monthly and daily averaged combined Terra and Aqua satellite fluxes and MODIS cloud properties combined with three-hourly, five-satellite geostationary derived broadband fluxes and cloud properties. The geostationary derived broadband fluxes are used to infer the flux in between the CERES observations on either Terra (10:30) or Aqua (1:30pm) satellites.

To ensure that the geostationary and MODIS cloud retrievals are consistent, the visible channel on the geostationary (GEO) imagers are first inter-calibrated against MODIS using coincident collocated radiances. This is performed over all-sky ocean, to reduce the effects of the spectral signature of the reflected visible radiance. The GEO visible radiances are then converted to broadband radiance using theoretical and empirical models. The resulting GEO broadband radiance is then converted to flux using the same angular directional models (ADM) that CERES uses (Loeb et al. 2003). The model type is based on the cloud conditions at the time of measurement. These 3-hourly GEO broadband fluxes are then temporally interpolated into hourly fluxes by using models that describe the change in albedo with solar zenith angle by using the albedos employed in deriving the CERES ADMs.

A shortwave (SW) regional normalization algorithm normalizes the GEO derived broadband flux to the CERES flux, which are coincident with 1.5 hours, in order to preserve the CERES instrument calibration in the SYN1deg flux product (Doelling et al. 2013). This procedure is different than the ISCCP FD approach, which computes the GEO fluxes directly from the GEO cloud properties (Zhang et al. 1995).

CERES is currently planning the release of Edition 4 flux products, which gives an opportunity to improve the existing GEO narrowband to broadband conversion procedure. The Edition 2 and 3 paradigms are to convert GEO narrowband radiances to MODIS-like 0.65µm visible radiances based on theoretical fits. The MODIS 0.65µm to broadband conversion is based on the CERES SSF coincident CERES footprint and MODIS 0.65µm imager radiance product. This empirical model is stratified by the same scene identification used in the CERES ADMs to improve the narrowband to broadband conversion. Some of the GEO narrowband channels are quite broad and the current approach may introduce more error than directly converting the GEO radiance to broadband radiance. However, some of the GEO visible imager channels are quite narrow, where the current approach maybe more applicable. These two approaches are compared in this study.

2 BACKGROUND

Over the last 12 years CERES has incorporated 15 GEO satellites and each GEO has a unique visible spectral response function (SRF). The older geostationary satellites have mainly broadband SRF as shown in figure 1. However, the newer satellites and future imagers will more closely resemble the MODIS narrowband channels. To complicate matters, the reflected SW radiance also has unique spectral signatures depending on scene type, a combination of surface and cloud types. The spectral reflection from a clear-sky desert is vastly different from clear-sky ocean or an overcast bright cloud.

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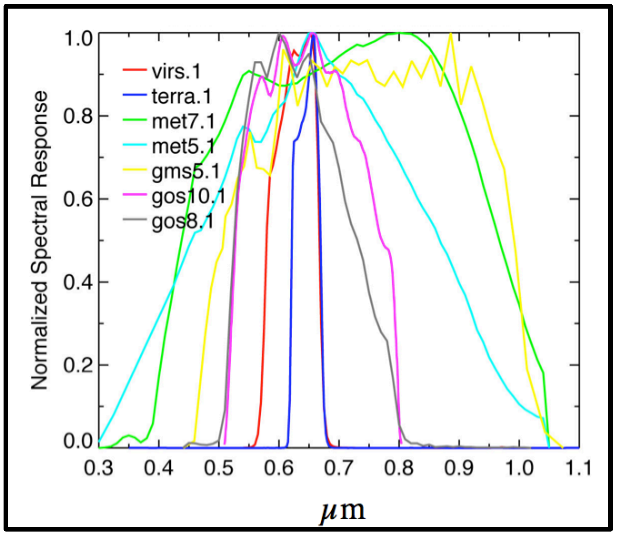

Figure 1. The visible spectral response functions of five geostationary satellites along with the MODIS 0.65μm channel onboard Terra and VIRS onboard TRMM. Note that Terra has a much narrower spectral response function.

3 METHODOLOGY

Two methods to convert GEO visible imager radiances to broadband radiances were evaluated. (1) The first method referred to as the empirical method, first converts the GEO imager radiance to an equivalent MODIS 0.65μm radiance using the radiative transfer model DISORT. The angular radiances were computed for various optical depths for a single layer for a liquid phase cloud residing between 2-3km and for an ice cloud located between 7 and 12 km using a mid-latitude summer profile. Only 3 surface types were considered, ocean, prairie, and desert. The equivalent MODIS 0.65μm band to broadband conversion is strictly empirical using coincident measured CERES radiances and collocated MODIS 0.65μm band radiances, using the same surface, cloud types, and angular conditions that the CERES ADM incorporates. Both MODIS and CERES are onboard the Terra and Aqua satellites. (2) The second method uses the same DISORT algorithm and cloud and surface conditions, except that the GEO radiances were converted to broadband fluxes in one step.

Since the GEO radiances are first gridded into 1° by 1° latitude by longitude regions, the conversion models must also be a function of cloud amount. The empirical model derived from CERES footprint radiances also contains the MODIS cloud fraction from which to construct the empirical model. The DISORT clear-sky and cloud reflectance is combined as function of cloud amount. Instead of deriving the narrowband to broadband reflectance coefficient based on incremental optical depth bins, the reflectance pairs over all optical depths for a given scene type and angular configuration are regressed linearly (figure 2). The narrowband to broadband conversion factor is mostly dependent on the brightness of the scene type, where bright clouds have a very different reflecance ratio then clear-sky conditions as shown in figure 2. Figure 2 clearly shows a broadband divided by narrowband ratio less than 1 for bright scenes and close to 1 for clear-sky ocean conditions. The advantage of this approach is that errors in the cloud retrieval will have less of an impact on the narrowband to broadband conversion process. For example, a thin cloud scene misidentified by the GEO retrieval algorithm as a clear scene will still obtain a robust narrowband to broadband ratio using the linear regression of the optical depth radiance pairs. Both methods use the same optical depth conversion technique.

4 RESULTS

The fluxes from both methods were evaluated during January 2010 using the five geostationary satellites in orbit during this time period: GOES-11, GOES-12, MTSAT-1, MET-7, and MET-9. The GEO derived broadband radiances are then converted to flux using the CERES ADMs as described in the introduction. Coincident within 15 minute regional GEO and CERES fluxes are matched and stratified according to angle and cloud properties and the resulting GEO minus CERES flux bias are shown in figure 3 and 4.

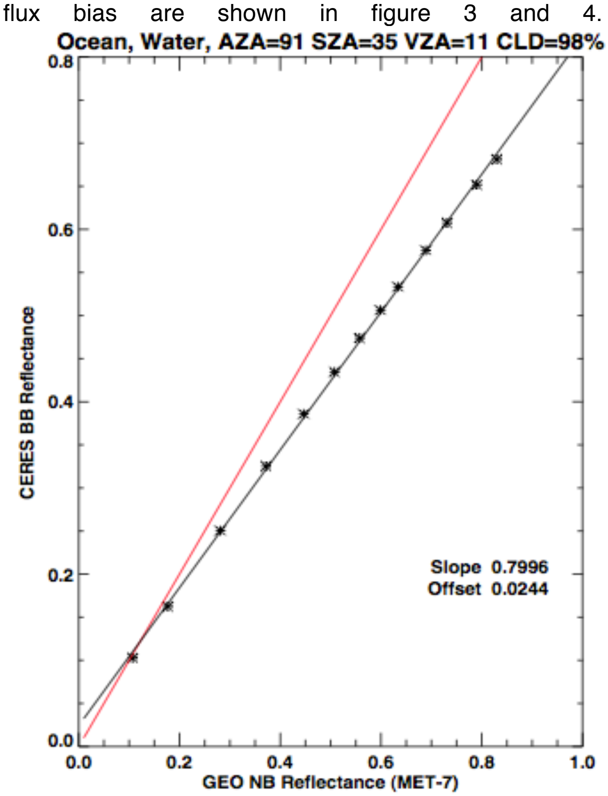

Figure 2. Modeled MET-7 visible and CERES broadband reflectance pairs based on various optical depth values for the cloud conditions stated on the title of the plot. The black line represents the linear regression of the reflectance pairs and the red line the 1 to 1 line.

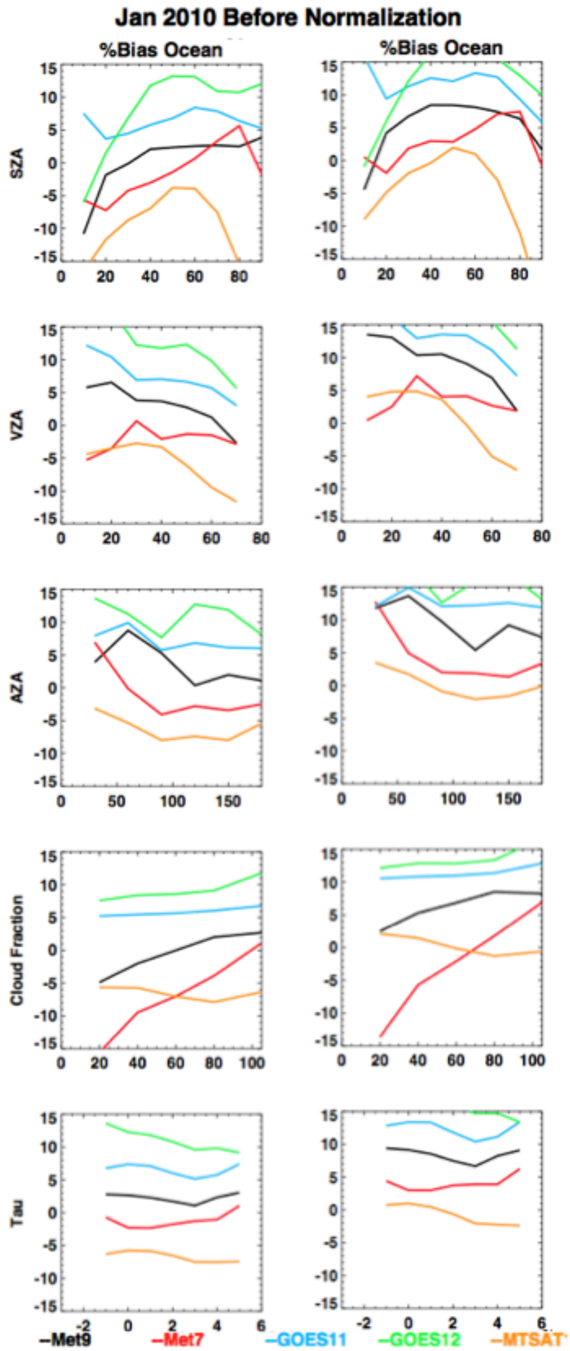

Figure 3. The January 2010 GEO derived broadband minus CERES measured flux bias (y-axis in percent) as a function of GEO solar zenith angle (SZA), view zenith angle (VZA), relative azimuth angle (AZA), cloud fraction, and optical depth (tau) (x-axis). Method 1 (empirical) and 2 (theoretical) results are shown on the left panels and right panels, respectively. The individual satellite line colors are labeled on the bottom of the figure. The results are before SW regional normalization.

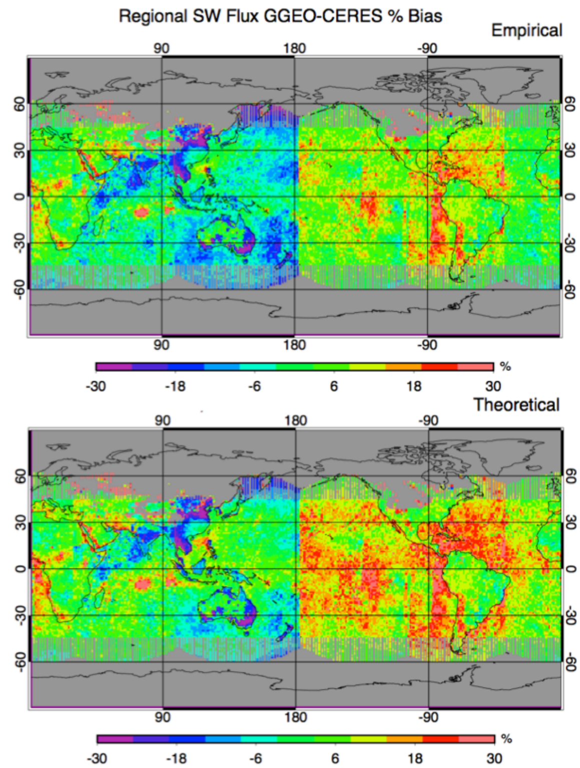

Figure 4. The January 2010 regional GEO derived broadband radiance minus CERES measured radiance bias in %. Method 1 (empirical) and 2 (theoretical) results are shown on the top and bottom, respectively.

If the narrowband to broadband radiance conversion were perfect the individual GEO flux biases would be zero. Figure 3 clearly shows that the GEO broadband derived fluxes biases are a strong function of angle. The GEO flux bias does not seem to be a strong function of optical depth and cloud fraction except for MET-7 located over the Indian Ocean. The individual GEO flux bias magnitudes vary as shown in both figures 3 and 4, implying that the both methods did not account spectral radiance not seen by the individual GEO SRF to derive the broadband radiance. Figure 4 clearly shows that the flux bias is a function of surface type and GEO satellite. The five GEO boundaries are clearly visible in figure 4.

The GEO to CERES SW regional normalization process then adjusts the regional GEO flux to match the CERES flux by applying conversion coefficients derived by linearly regressing the coincident instantaneous fluxes over the course of the month over a 5° by 5° latitude by longitude domain over the same surface type (Doelling et al. 2013). Figure 5 and 6 show the impact of normalization. The GEO flux bias is within 3% across all angles and cloud properties. The associated RMS error is within 20%. Figure 6 shows the regional biases have almost disappeared except over glint regions along the equator.

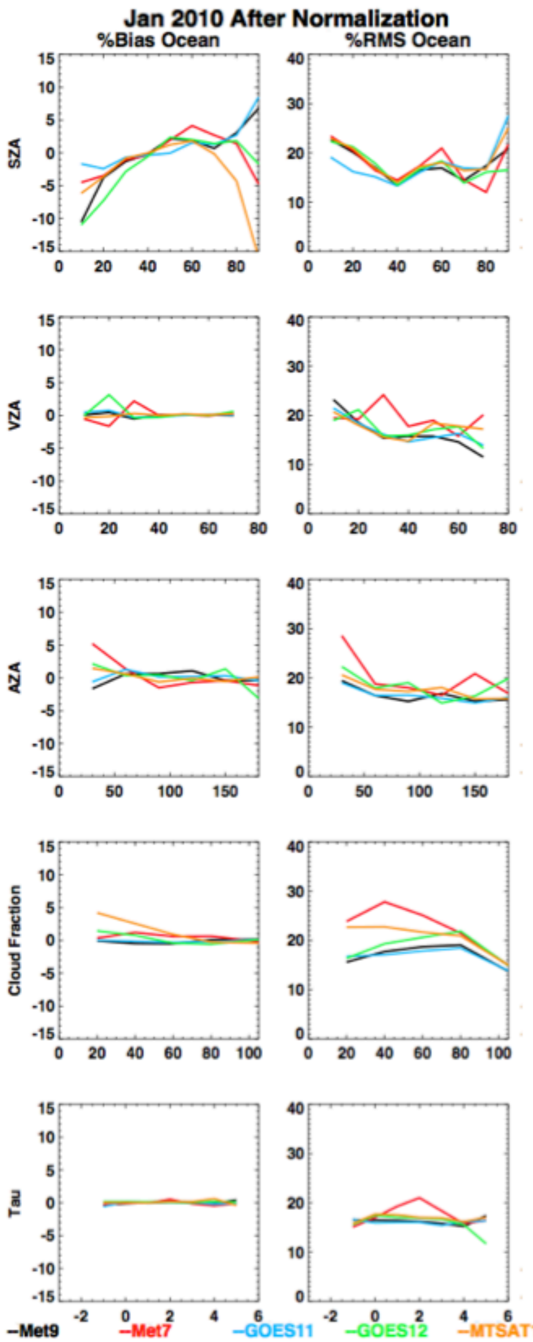

Figure 5. Same as figure 3 except for after SW regional normalization using method 1 empirical narrowband to broadband radiances. The left and right panel plots show the GEO minus CERES flux bias (%) and RMS error (%), respectively.

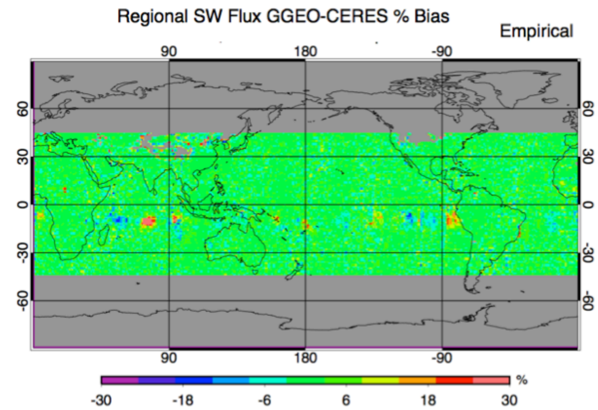

Figure 6. Same as figure 4, except for after SW regional normalization for method 1 (empirical).

4 CONCLUSIONS

Two methods were used to convert the GEO imager radiances to CERES radiances. One method converted the GEO radiances to an equivalent MODIS 0.65 μm band radiances using DISORT and then using an empirical model based on coincident MODIS and CERES radiance measurements. The second method converted the GEO narrowband to broadband radiance directly. Method 1 was a slightly better than method 2 when compared as a function of angle and cloud property. However the regional SW GEO to CERES flux normalization algorithm removed most angular and cloud property dependencies of the GEO derived broadband flux. These GEO fluxes are part of the CERES SYN1deg product to account for the diurnal cycle in between CERES measurements and are of climate quality.

4 REFERENCES

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