13.1 COMPARISONS OF GERB AND CERES MEASUREMENTS

Pamela E. Mlynczak* and Z. Peter Szewczyk
Science Applications International Corporation, Hampton, VA

G. Louis Smith
National Institute of Aerospace, Hampton, VA

Jacqueline E. Russell and John E. Harries
Blackett Laboratory, Imperial College, London, United Kingdom

Steven Dewitte and Nicolas Clerbaux
Royal Meteorological Institute of Belgium, Brussels, Belgium

1. INTRODUCTION

The Geostationary Earth Radiation Budget (GERB) is the first broadband radiometer to be placed into geosynchronous orbit in order to measure the flux of solar radiation reflected from the Earth and the radiative flux emitted from Earth (Harries et al., 2000; Harries et al.; 2005). The GERB is on board the first MeteoSat Second Generation (MSG-1) spacecraft, which was placed into orbit in August 2002 and is now named Meteosat-8. From its position 35,800 km above the Equator near 0° longitude, GERB provides measurements of reflected solar radiances (RSR) and outgoing longwave radiances (OLR) every 15 minutes over the portion of the Earth which is visible from that position, at a resolution of approximately ½° latitude and longitude at the sub-satellite point of GERB. These data will provide unprecedented information about the energetics of processes which occur on time scales of a day or shorter, as indicated in fig. 1. Instruments aboard a polar orbiter cannot provide the multiple views each day to resolve processes on these short time scales. These processes include the diurnal cycle of the heating and cooling of the part of the Earth within its field of view. This view encompasses the Sahara Desert, which has the greatest range of diurnal cycle of OLR over the planet, and the Inter-tropical Convergence Zone (ITCZ), which moves over northwest Africa in boreal summer and back to the tropical Atlantic Ocean for the remainder of the year. Absorbed solar radiation is the source of sensible and latent heat, and OLR furnishes the heat sink, which together drive the dynamics and rainfall of these regions. GERB is the only instrument in geostationary orbit that measures broadband radiances for radiation budget studies of weather and climate processes.

In order to measure radiances over the full disc of the Earth with ½° degree resolution in latitude and longitude (near the sub-satellite point) every 15 minutes, the GERB instrument uses an array of 256 detectors that give 256 total radiance channels and 256 RSR channels when a quartz filter is in the optical path. The detector array is oriented parallel to the spin axis of the spacecraft. A despin mirror stops the image on the array at successive locations, so as to cover the Earth's disc in 282 scans.

It is necessary to compare the results from each of the 256 channels for the RSR and the OLR in order to validate that they are providing comparable results, and also to compare them against other satellite radiometers to establish the GERB calibration relative to other radiometers for climate research. At present, the only broadband satellite radiometers against which to compare GERB measurements are the Clouds and Earth Radiation System (CERES) instruments (Wielicki et al., 1996). CERES instruments have operated on the Terra spacecraft since February 2000 and aboard the Aqua spacecraft since June 2002 (Smith et al., 2004). In these comparisons, the CERES radiometer is regarded as a transfer radiometer, with no claim to being the "True" measurement. It must be remembered that in any comparison of measurements, both instruments are being validated.

The radiance from an Earth scene varies with the viewing direction, thus to compare radiances, both instruments must view the scene from the same viewing angle at nearly the same time. Comparison of radiances in different directions would require use of a model of the directionality of the RSR, which would introduce errors that are typically larger than the instrument errors. The

Corresponding author address:
Pamela E. Mlynczak, SAIC, 1 Enterprise Parkway, Suite 300, Hampton, VA 23666.
E-mail: p.e.mlynczak@larc.nasa.gov

CERES instruments have the capability to operate with the azimuth programmed to vary in a prescribed manner as the spacecraft moves along its orbit. To date there have been four campaigns in which the CERES FM-2 aboard the Terra spacecraft has been operated so as to align with GERB as Terra passes over the part of the Earth viewed by GERB. These campaigns took place during solstices, so as to maximize the insolation of the Northern and Southern Hemispheres in turn. This paper presents results for the comparison of GERB and CERES shortwave radiances for two campaigns. At this time, GERB measurements have been reprocessed only for these two campaigns, and the GERB data used is a pre-release version.

2. TECHNIQUE FOR COMPARING RADIANCES

Figure 2 shows the geometry for the alignment of GERB and CERES. The MeteoSat-8 spacecraft, on which GERB rides, is at an altitude of 35,800 km, and CERES/Terra is at 705 km. The line from GERB through CERES is the unique line for which both instruments view the same radiance from an Earth scene at a given time. As Terra moves over the Earth, the line of alignment moves also. The scan axis of the CERES instrument is horizontal, so that the scan plane is vertical, i.e. always includes the center of the Earth. The axis can be rotated about nadir to any desired azimuth. The scan axis is rotated so that the scan plane contains the GERB spacecraft, thereby defining the plane by the three points: CERES, GERB and the center of the Earth. The line of alignment lies within the scan plane thus defined. During each scan, the CERES line of sight will coincide with the alignment line, thereby providing the desired radiance measurement (Smith et al., 2003).

The footprint sizes for GERB and CERES depend on the distance of the scene from nadir. At nadir, the GERB footprint is approximately 40 km, and the CERES footprint is 20 km. As the instruments scan from nadir, the CERES footprint grows much faster than does the GERB footprint. At an Earth central angle of 60°, the footprints of both instruments have grown to 100 km and for distances further than 61°, the CERES footprint is larger than that of the GERB. As a consequence, near nadir a GERB pixel will be spanned by two CERES pixels, and near 60° Earth central angle, the CERES and GERB footprints are of comparable sizes. For an Earth central angle beyond 70°, the CERES footprint is considerably larger than that of GERB.

Pixels are used for which the view zenith angle and azimuth angle between the CERES and GERB locations agree within five degrees. When Terra flies nearly under GERB, the azimuth angle can vary considerably due to the polar singularity, so if the angle between the ray from the Earth scene to CERES and the ray from the Earth scene to GERB is less than ten degrees, the match is accepted. The reflected solar radiation does not vary sufficiently within these angle ranges to create a large error, whereas the increased number of measurements greatly reduces scatter in the results.

For comparison of GERB and CERES measurements, it is desirable to obtain measurements near the June solstice to get maximum insolation in the Northern Hemisphere and near the December solstice to get maximum insolation in the Southern Hemisphere. The CERES FM-2 instrument, aboard the Terra spacecraft, has been operated in programmable azimuth plane scanning (PAPS) mode to align with GERB observations for four major campaigns. The first was in December 2003 and January 2004, which provided data for 15 days. The next special operation of CERES for the GERB comparison was in June and July 2004, during which data were collected for 27 days. The third campaign was conducted in December 2004 through January 2005, for 27 days of data. In June 2005, data were gathered for 21 days using FM-2 in PAPS mode. FM-2 was also operated in a restricted PAPS mode in December 2005, which produced much less data in the Southern Hemisphere where the insolation is greatest.

3. RESULTS

The number of matches of CERES measurements with GERB measurements that were obtained for a week during each of the June 2004 and December 2004 campaigns is shown by fig. 3. The mean shortwave radiances for matching CERES and GERB measurements are shown by fig. 4. The effects of latitude on insolation and the corresponding mean radiance measurements for the two data periods are dramatic, emphasizing the need to have the campaigns during each solstice. The GERB measurements are slightly above the CERES measurements for most detectors.

Figure 5 shows the differences between GERB and CERES measurements for each GERB detector for the week in June and in December 2004. For mid-latitudes the differences are mostly two to six W-m^{-2}-sr^{-1}. The error bars indicate the range which contains the true difference with 95% probability for each detector. At the ends of the detector array, i.e. for detectors with the lowest and highest numbers, the differences and their errors are small at the winter end and large at the summer end, in proportion to the shortwave radiances and the insolation.

For each campaign, the mean GERB measurements are divided by the mean CERES measurements for each detector to give the gains of the GERB detectors relative to the CERES radiometer. Figure 6 shows this ratio of GERB to CERES shortwave measurements for each detector for 11 to 17 June 2004 and for 21 to 27 December 2004. For detectors 32 through 224, the average ratio is 1.05, with a range from 1.02 to 1.07 covering most cases. Error bars indicate the plus and minus one-sigma ranges for each detector. For detectors 45 through 145 there is a long-range structure with a short-range variation that looks random. For detectors 145 to 250 the variation is larger and appears as simply uncorrelated random variations.

In figs. 5 a and b the difference between GERB and CERES measurements changes from one detector to the next by more than one would expect due to sampling errors, raising the question of how much do the GERB detectors vary among themselves. The question also applies to fig. 6 for the relative gains of the GERB and CERES radiometers. To address this question, the radiance for each detector is averaged over all column positions for a number of GERB images of Earth. Figure 7 shows the number of radiance measurements used to form the mean radiance for each detector. The mean radiance of each detector is subtracted from that of the adjacent detector. Figure 8 shows these detector-to-detector differences for the two test weeks in June and December 2004. The differences in fig. 8 appear to be consistent with the short-range seemingly random variations from one detector to the next which are seen in fig. 5. This line of reasoning regarding detector-to-detector differences assumes that when the radiances from Earth are averaged over all columns for each detector, the resulting mean radiance distribution is smooth from north to south, so that the latitudinal variations are small from one detector to the next.

4. CONCLUSIONS

The CERES FM-2 instrument on the Terra spacecraft was operated in the programmable azimuth plane scanning mode so as to align with GERB to measure the same radiances from Earth scenes during four campaigns. These campaigns were in two Northern Hemisphere winters and two Northern Hemisphere summers. The CERES radiometer serves as a transfer radiometer for comparing the GERB detectors. Results are shown for detectors 49 to 174. For detectors 1 to 48 (the northern-most part of the array) and 175 to 256 (the southern-most part), the sampling is inadequate and the results are not as good.

For shortwave radiances, the detectors vary by ±2% among themselves. Between adjacent detectors, there is a random uncorrelated change of about ½% and a long-range structure (over a score or more) of ±2% superimposed. Comparisons are reproducible within 1% among the campaigns, showing a very small change of retrieved shortwave radiances.

This paper has presented results from two campaigns of the four major campaigns that have been conducted thus far. Other campaigns have been analyzed, helping to lead to the modification of instrument parameters in the processing system so that the early data products are obsolete. As earlier data are reprocessed, comparisons can be made for those time periods. Future campaigns must be performed in order to evaluate changes of the instruments. Also, the second GERB instrument is now in orbit aboard the MeteoSat-9, so that validation is needed for that instrument.

5. ACKNOWLEDGEMENTS

The Earth Science Enterprise and the Langley Research Center of NASA supported the work of GLS, PEM and ZPS. CERES data were obtained from the NASA Langley Research Center Atmospheric Science Data Center. GERB data were obtained from the GERB Ground Segment Processing System at the Rutherford Appleton Laboratory, United Kingdom, and from the Royal Meteorological Institute of Belgium.

6. REFERENCES

Harries, J. E., J. E. Russell, J. A. Hanafin, H. Brindley, J. Futyan, J. Rufus, S. Kellock, G. Matthews, R. Wrigley, A. Last, J. Mueller, R. Mossavati, J. Ashmall, E. Sawyer, D. Parker, M. Caldwell, P. M. Allan, A. Smith, M. J. Bates, B. Coan, B. C. Stewart, D. R. Lepine, L. A. Cornwall, D. R. Corney, M. J. Ricketts, D. Drummond, D. Smart, R. Cutler, S. Dewitte, N. Clerbaux, L. Gonzalez, A. Ipe, C. Bertrand, A. Joukoff, D. Crommelynck, N. Nelms, D. T. Llewellyn-Jones, G. Butcher, G. L. Smith, Z. P.

Szewczyk, P. E. Mlynczak, A. Slingo, R. P. Allan, and M. A. Ringer, 2005: The Geostationary Earth Radiation Budget (GERB) Project, *Bull. Amer. Met. Soc.*, **86**, 945-960.

Harries, J. E., C. Naud and H. Brindley, 2000: The Geostationary Earth Radiation Budget (GERB) experiment: Science applications, *Proc. Internat. Rad. Symp.*, St. Petersburg.

Smith, G. L., Z. P. Szewczyk, P. E. Mlynczak, R. B. Lee III, B. A. Wielicki, K. J. Priestley, J. Harries, S. Dewitte, and N. Clerbaux, 2003: Method for comparison of GERB and CERES radiances, *Proc. SPIE*, **5234**, 423-432.

Smith, G. L., B. A. Wielicki, B. R. Barkstrom, R. B. Lee III, K. J. Priestley, T. P. Charlock, P. Minnis, D. P Kratz, and N. G. Loeb, 2004: Clouds and Earth Radiant Energy System (CERES): An Overview," *Adv. Space Res.,* **33**, 1125-1131.

Wielicki, B. A., B. R. Barkstrom, E. F. Harrison, R. B. Lee III, G. L. Smith, and J. E. Cooper, 1996: Clouds and the Earth's Radiant Energy System (CERES): an Earth observing system experiment, *Bull. Amer. Met. Soc.*, **77**, 853-868.

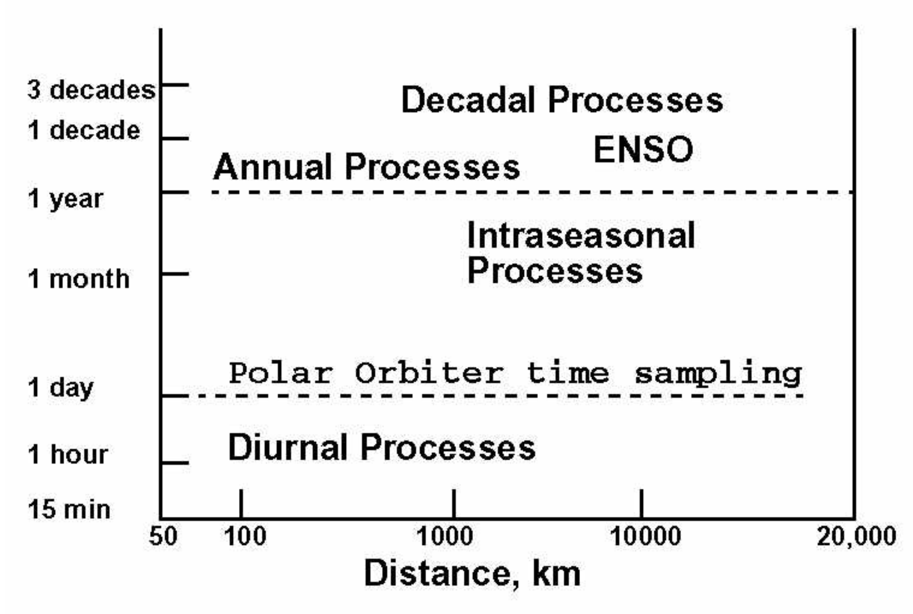
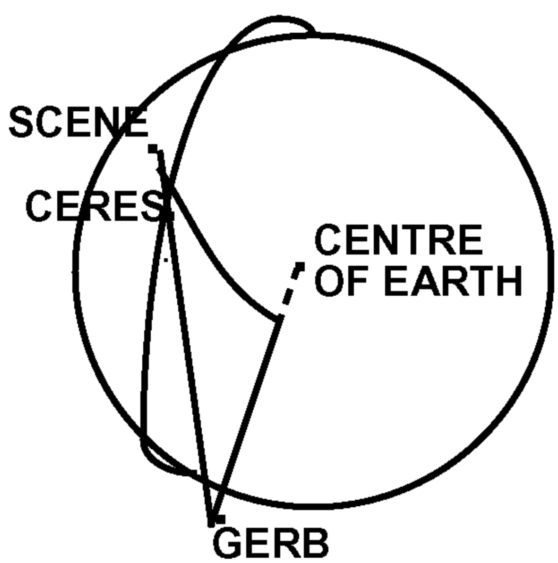


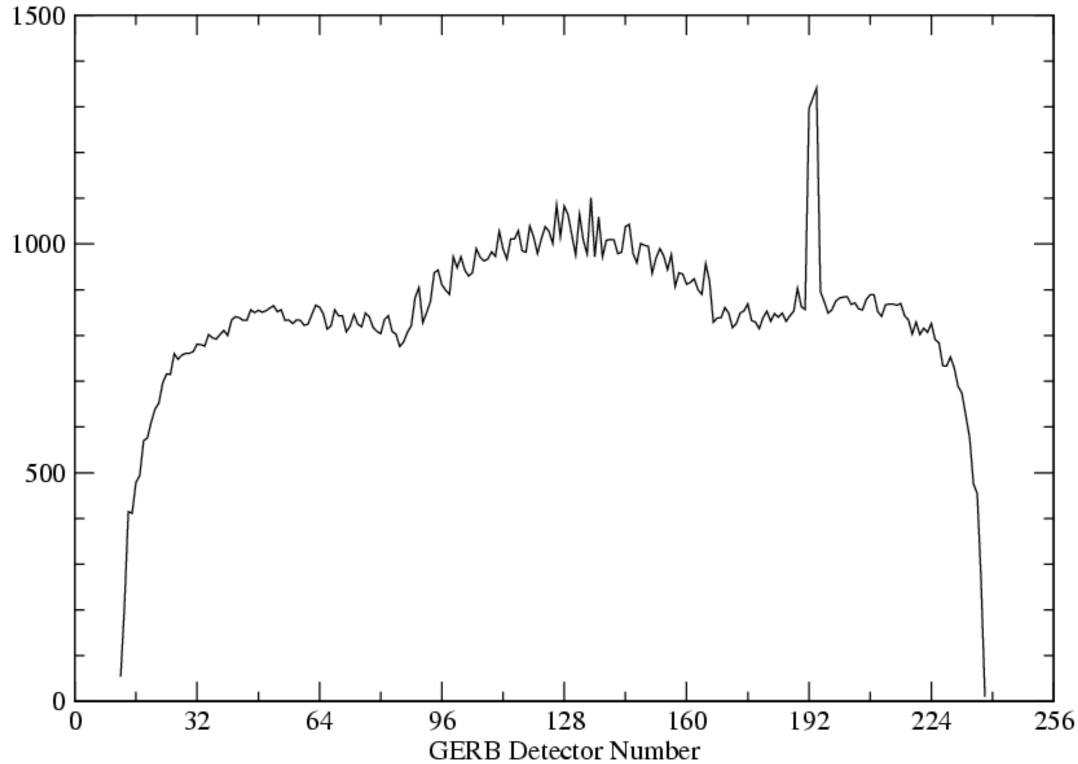
Figure 1. Time scales of weather and climate processes and observation limits of spacecraft.



#

Figure 2: Rotation of CERES scan plane to contain GERB assures that one Earth scene in the scan will be viewed by both GERB and CERES.

a)



b)

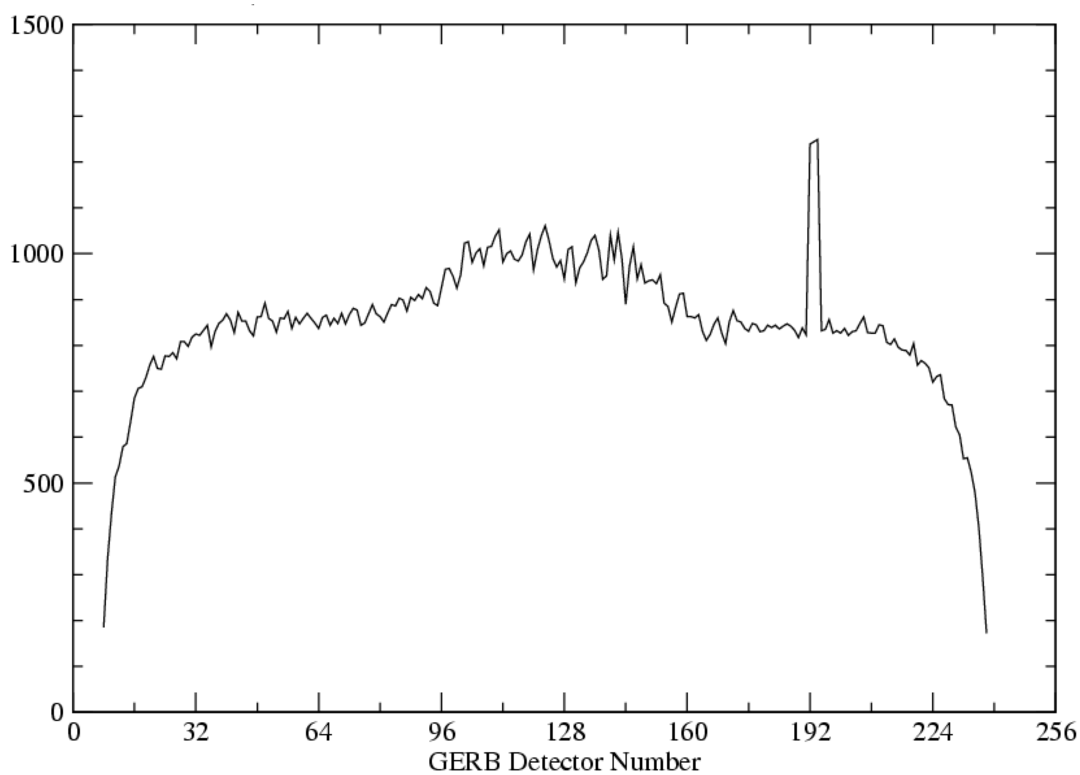
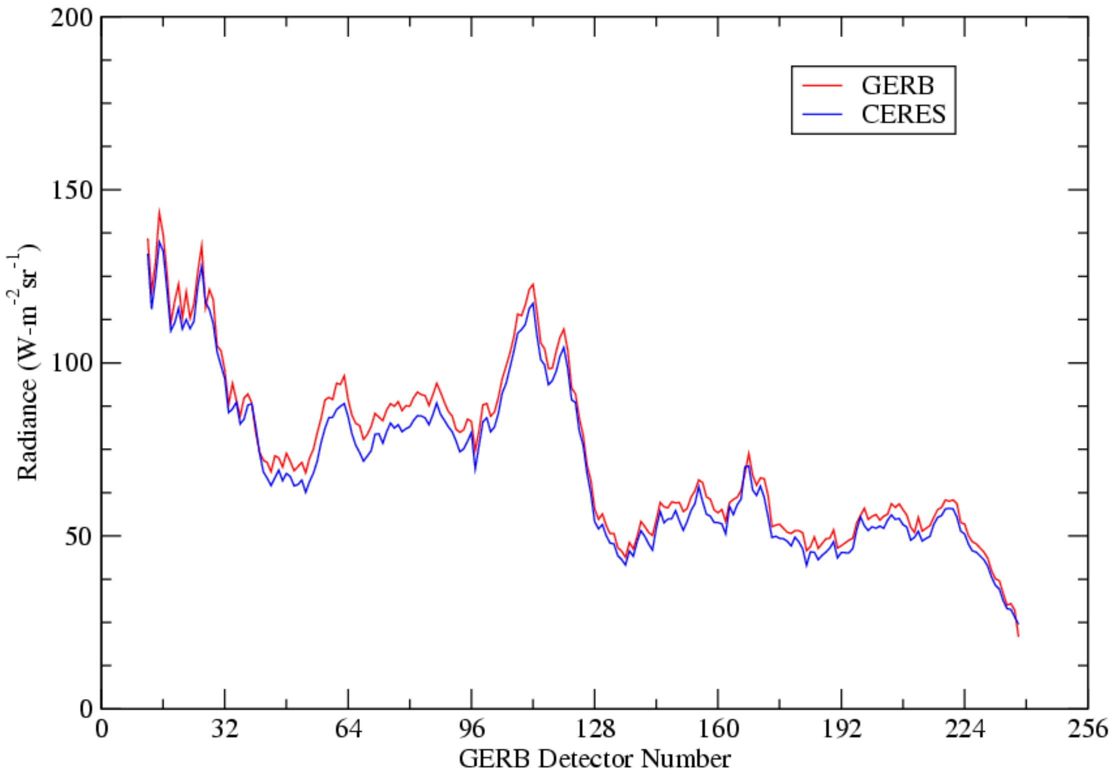


Figure 3. Number of CERES measurements that match each GERB detector for a) June 21-27, 2004 and b) December 11-17, 2004.

a)



b)

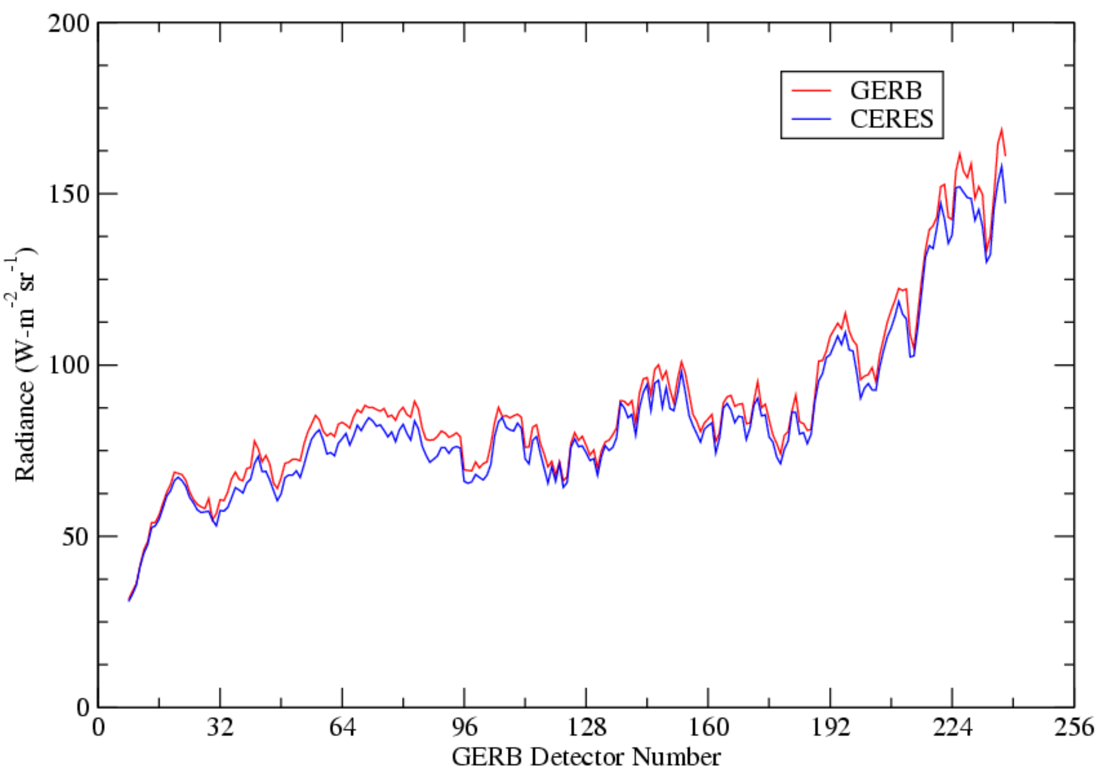
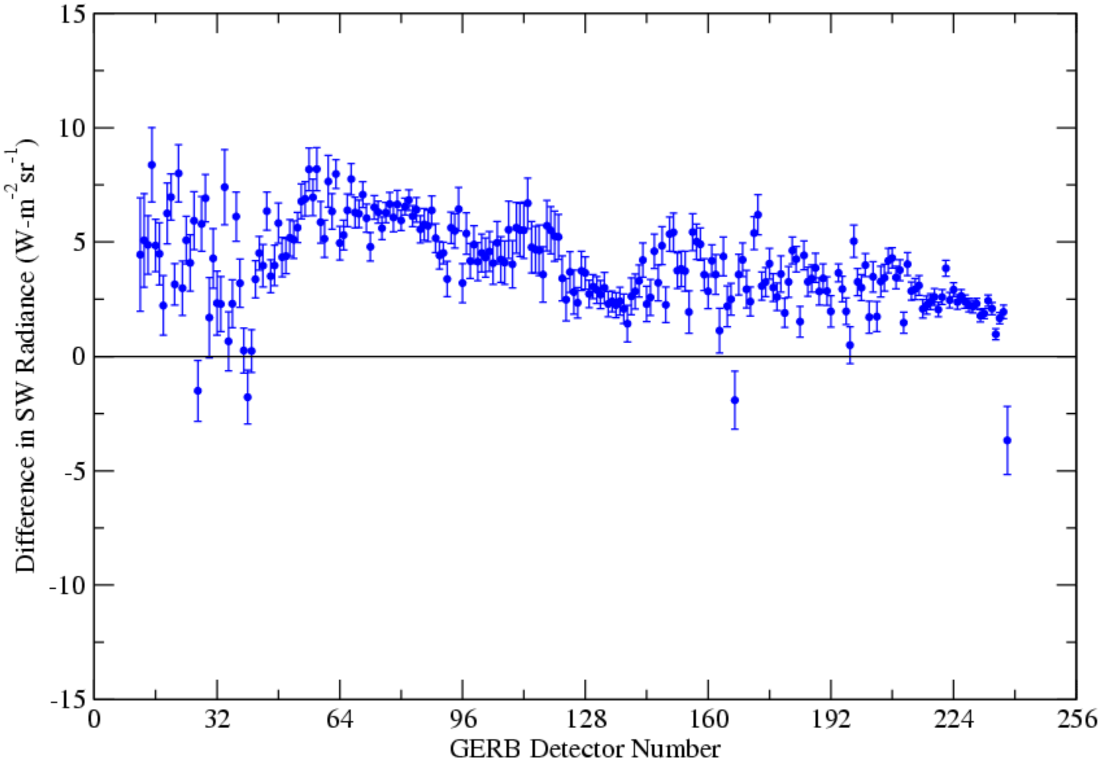


Figure 4. Average shortwave radiance measurements for matching GERB and CERES pixels for a) June 21-27, 2004 and b) December 11-17, 2004.

a)



b)

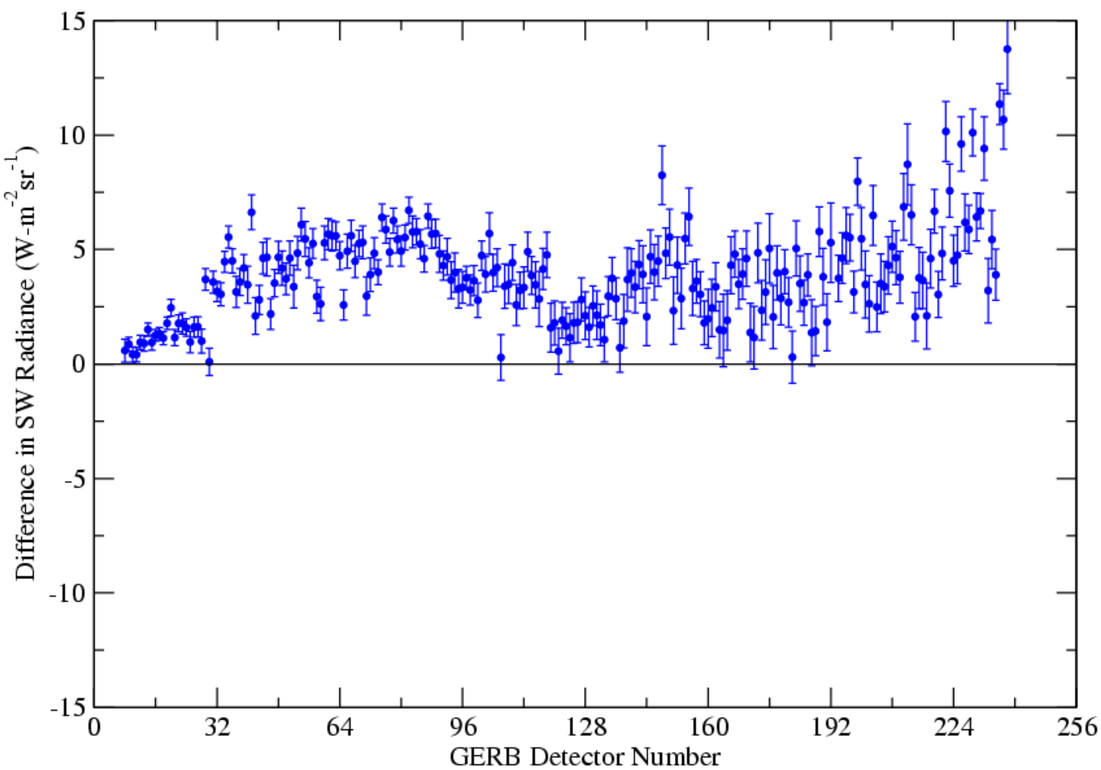
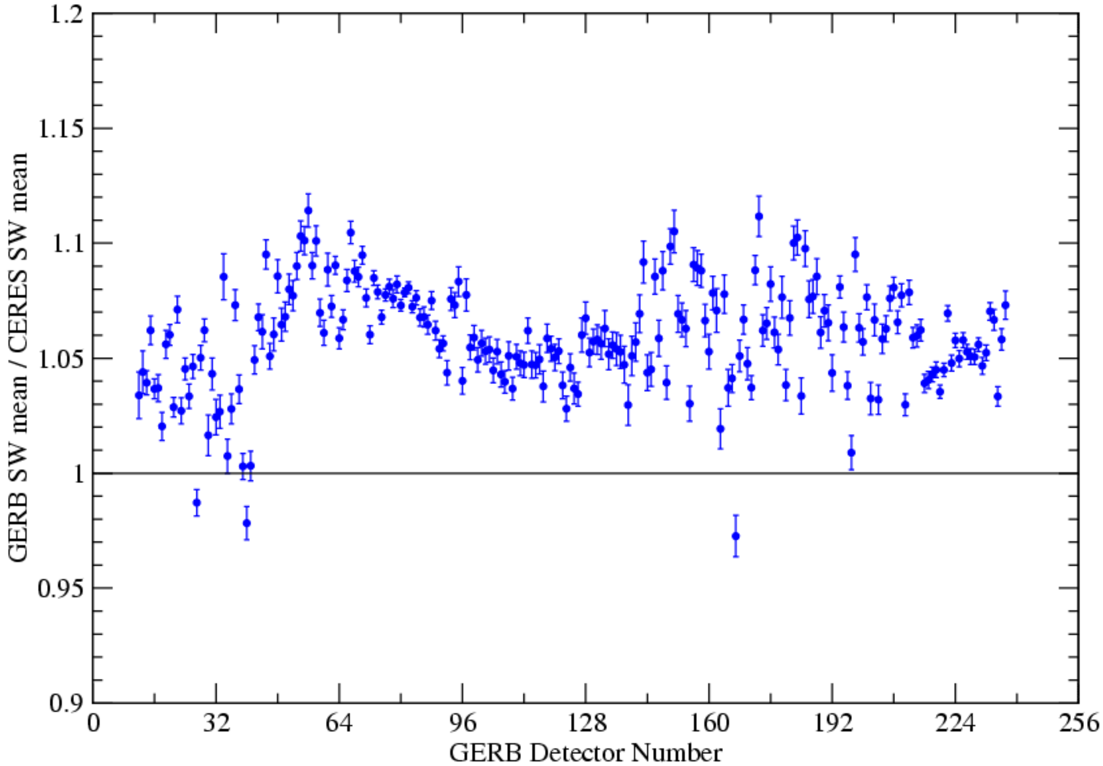


Figure 5. Difference between matching GERB and CERES average shortwave measurements for each GERB detector for a) June 21-27, 2004 and b) December 11-17, 2004.

a)



b)

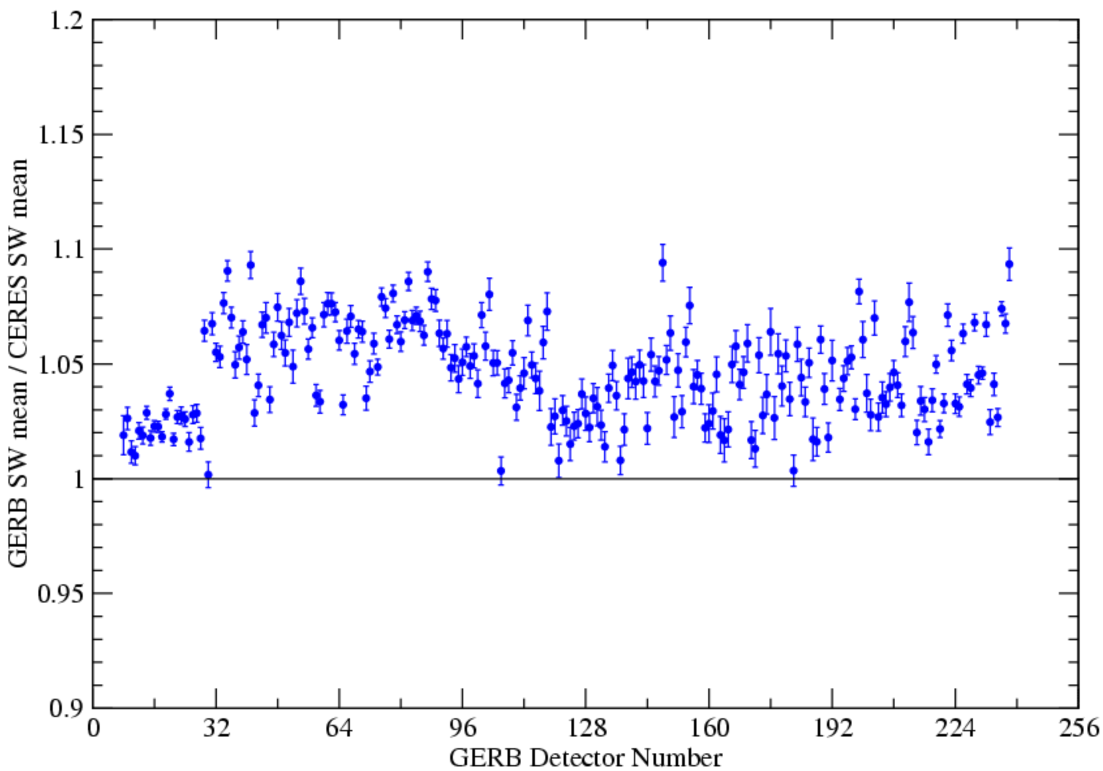
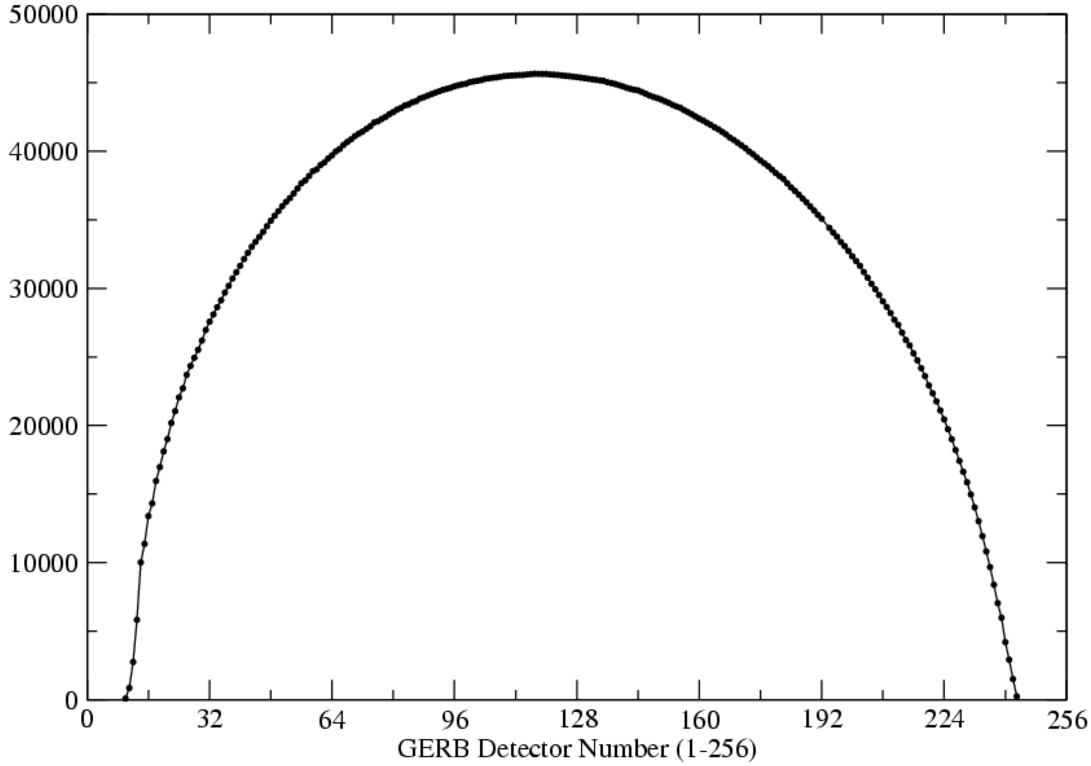


Figure 6. Ratio of GERB mean radiances to matching CERES mean radiances for each detector for a) June 21-27, 2004 and b) December 11-17, 2004.

a)



b)

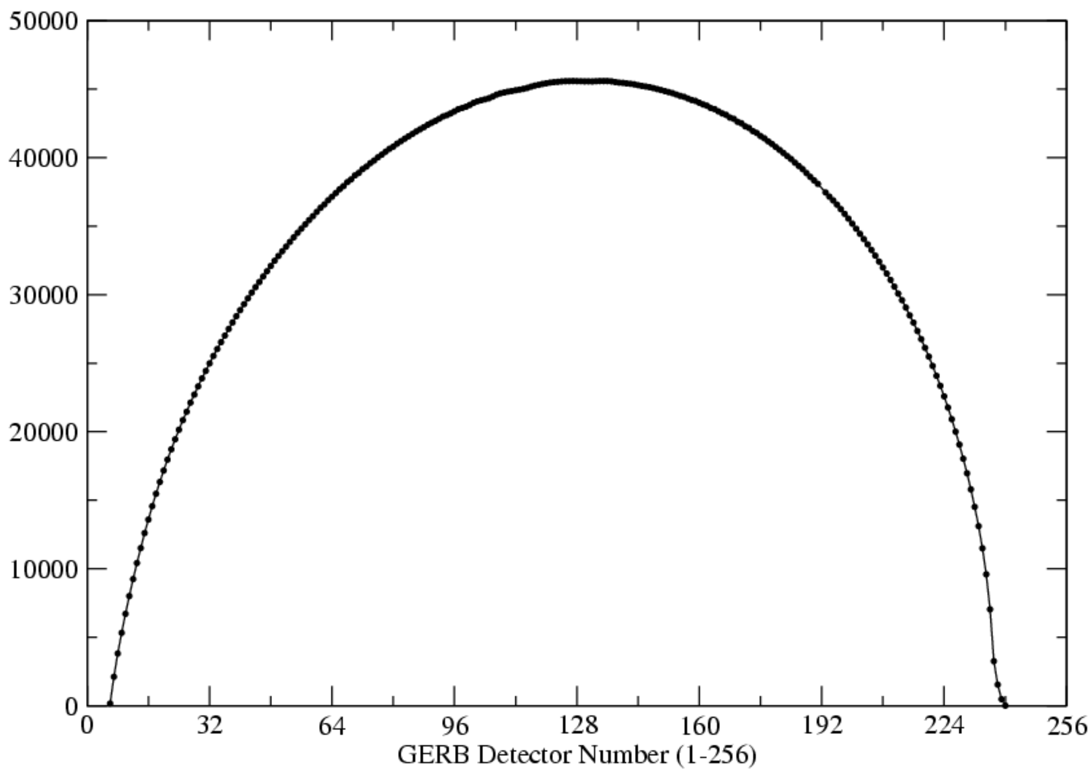


Figure 7. Number of GERB measurements for each detector used to form mean shortwave radiance for detector-to-detector difference computation for a) June 21-27, 2004 and b) December 11-17, 2004.

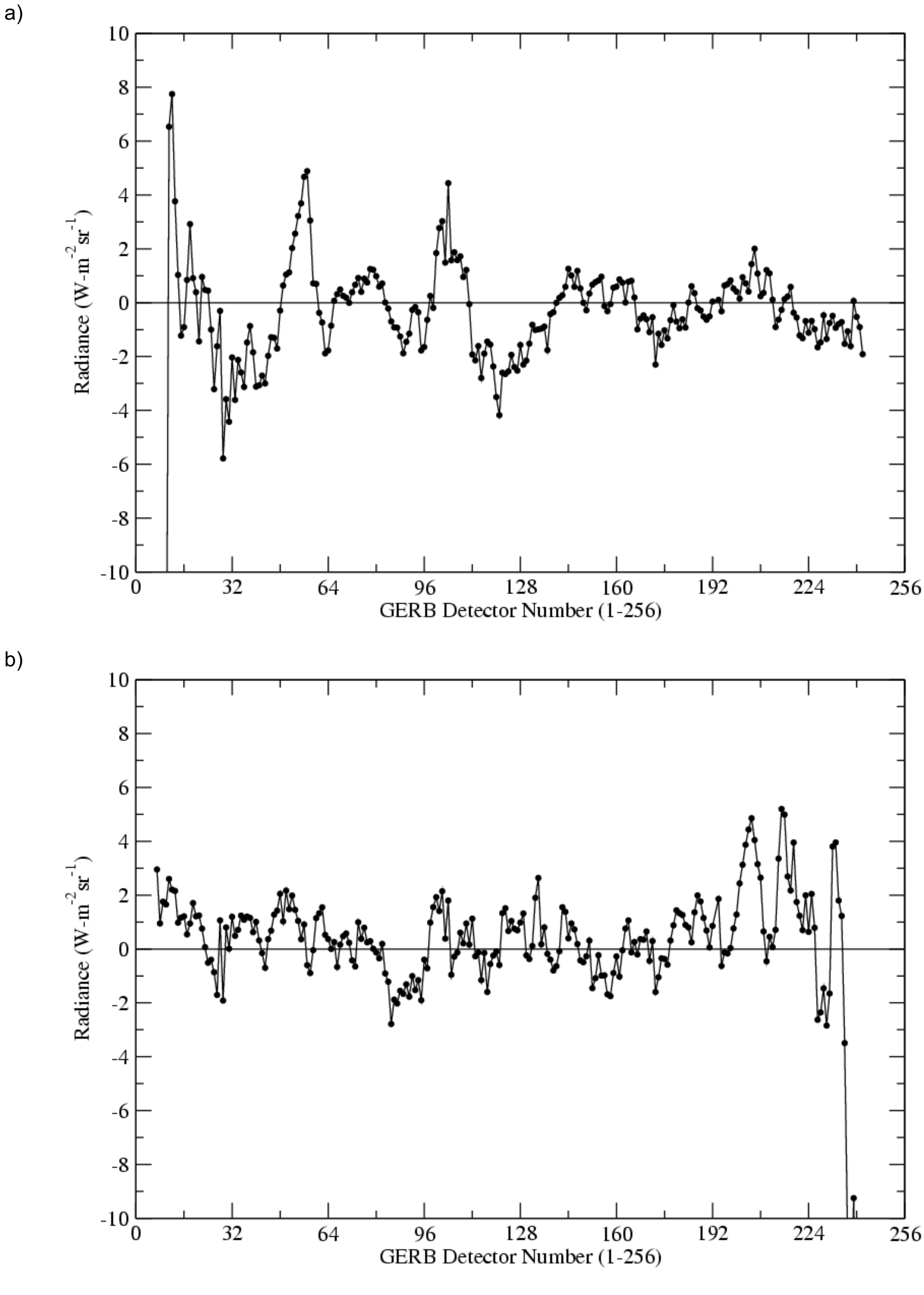


Figure 8. Differences in mean shortwave radiance between adjacent GERB detectors for a) 21-27 June 2004 and b) 11-17 December 2004.