The Next Decade of Earth Radiation Budget Measurement

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Abstract

Measurements of the Earth's radiation budget are necessary for understanding our climate and for monitoring its changes. Clouds and Earth Radiant Energy System (CERES) scanning radiometers have operated on the Terra spacecraft since 2000 and on the Aqua spacecraft since 2002. A CERES instrument, Flight Model 5, is now scheduled to fly on the NPOESS Preparatory Project spacecraft, with launch readiness in 2010. FM-5 has been vacuum-tested, calibrated and shipped for integration to the NPP spacecraft. Another CERES instrument, Flight Model 6, will be assembled and will fly on the NPOESS C1 platform, with launch readiness in 2013. The next step in the continuation of Earth radiation budget measurements is the development of a successor to the CERES instruments. The first model of that instrument is planned for flight on the NPOESS C3 platform with launch readiness in 2018. It is planned that each of these missions will overlap so that the climate data record of radiation budget will be seamless. By the flight of the NPP, the CERES and Earth Radiation Budget Experiment records will span a quarter of a century, enabling studies of climate variations with periods of decades.

1. INTRODUCTION

Climate and the absorption of solar energy by the Earth and its reemission as longwave radiation are closely coupled, such that in order to be aware of climate variations and to understand their causes and effects, it is necessary to monitor these radiation streams on a continuing global basis. The changes of radiation associated with variations of climate on time scales from interannual through decadal to longer times are small, so that accurate measurements are required. The Clouds and Earth Raiation Energy System (CERES) project (Wielicki et al., 1996) was formed to provide radiation measurements. The Terra spacecraft carried CERES Flight Model 1 and 2 instruments into orbit in December 1999 (Priestley et al., 2000). The Aqua spacecraft went into orbit in May 2002 with CERES FM-3 and -4 (Priestley et al., 2007). The design life of the Terra and Aqua spacecraft is seven years and Terra is already operating as an Extended Mission. In order to continue the Earth radiation budget record into the future, plans call for CERES-type instruments to fly on the NPOESS Preparatory Platform and on the NPOESS spacecraft.

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Radiation budget information was identified as a Critical Data Record in the 2007 Global Observing System Report of the World Climate Research Program. In its 2007 Decadal Survey, the National Research Council took the stand that "Measurements of total solar irradiance and Earth radiation recently eliminated from NPOESS should be restored…to avoid a measurement gap in the time frame 2008 to 2012." The NPOESS will not fly by 2012, so the "Impacts of NPOESS Nunn-McCurdy Certification on Joint NASA-NOAA Climate Goals" in January 2007 stated that 'Measurements of total solar irradiation and Earth radiation recently eliminated from NPOESS should be restored on NPOESS or provided by other means to avoid a measurement gap in the time frame 2008 to 2012." NASA directed the NPOESS Preparatory Project (NPP) to prepare the Clouds and the Earth's Radiant Energy System (CERES) Flight Model 5 (FM-5) sensor for flight on the NPP spacecraft for launch readiness in June 2010.

This paper explains the necessity of flying the FM-5 on this platform and discusses some of the opportunities to join the FM-5 data record with those of other instruments. It will also be necessary to include CERES type instruments on the NPOESS spacecraft to extend the Earth radiation budget climate data set beyond the life of the NPP platform in order to understand the climate as it changes due to global warming, which is one of the greatest challenges of the twenty-first century.

2. CLOUDS AND THE EARTH RADIANT ENERGY SYTEM (CERES)

The Earth Radiation Budget Experiment (ERBE) was formed in response to a call from the scientific community for information about the balance of solar radiation absorbed by the Earth and the radiation emitted by the Earth (Barkstrom and Smith, 1986). This project flew instrument packages on the operational NOAA-9 and NOAA-10 spacecraft and the dedicated Earth Radiation Budget Satellite. Because of the value of the information derived from the ERBE data, the CERES project was formed to continue this radiation data set, to improve it and to extend the derived information through the atmosphere and to the surface (Wielicki et al., 1996). CERES furnishes the only current climate-quality data set for shortwave and longwave fluxes that drive climate. These data provide the integral constraints in the energetics of the atmosphere-ocean-cryosphere system as it absorbs solar heat and emits it as OLR. Cloud cover and temperature and humidity profiles are retrieved from satellite imager and sounder data, after which the OLR and reflected solar radiation fluxes can be computed by use of a radiation transfer model. The fluxes as measured by CERES supply the check on these calculations.

The CERES instrument design is based on the ERBE scanning radiometer, with improvements where possible. CERES measures radiances at the spacecraft with a total channel (0.2 μ through 50 μ), and shortwave channel (0.2 to 5.0 μ) and a window channel (8 to 12 μ). From the measurements, the radiances at the spacecraft are computed, whence the flux at the "top of the atmosphere" is computed. The CERES data processing system also ingests ancillary data to compute for the first time the flux through the atmosphere and the flux at the surface. These results are located on an Earth grid system then spatially averaged over each grid element to make maps at the time of measurement. These maps are temporally interpolated to make daily maps, then they are temporally averaged to get monthly mean radiation flux maps. Each step requires quality assurance and validation.

It was required that CERES provide radiation fluxes at the top of the atmosphere which are three times as accurate as those of ERBE. Computing radiation fluxes at the top of the atmosphere accurately requires not only the measurements of radiances from CERES but also ancillary information to account for the anisotropy of the radiation. Clouds strongly affect the directionality of radiation, thus cloud imager data are needed. Aerosols also influence the anisotropy, though not so much as clouds. For surface radiation fluxes and fluxes through the atmosphere, the surface temperature and profiles of temperature and humidity are needed. These data sets permit the calculation of fluxes at the times of observation.

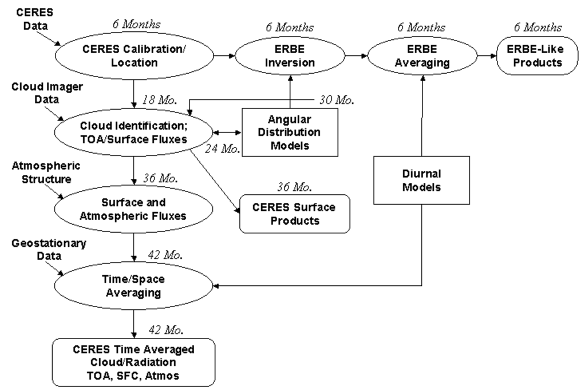

Figure 1 Data Flow for CERES Data Processing System

The atmosphere changes rapidly during the day, so that computing the daily averages of these fluxes accurately requires geostationary imager data around the Earth for diurnal interpolation. Data from up to eleven instruments on seven spacecraft are integrated to obtain radiation fluxes at the top of the atmosphere, through the atmosphere and at the surface with the accuracy demanded for climate research. Figure 1 shows the data flow for the CERES Data Processing System.

3. CERES FLIGHT MODEL-5 ON NPP SPACECRAFT

Currently the earliest NPOESS launch is in 2013. By then the Terra and the CERES instruments aboard it have been operating for 13 years and the Aqua with its CERES instruments will have 11 years of use. A risk analysis has shown that the probability that none of the instrument-data system-spacecraft systems operate by 2013 is quite high. This resulting gap in the climate data record would be unacceptable. The long time between Aqua and NPOESS. necessitates including the CERES FM-5 on the NPP spacecraft, which is scheduled for flight in 2010.

The CERES FM-5 was built for to use for an EOS follow-on mission and has been in storage at Northrop-Grumann Space Technology Division since 1999. It has been tested periodically every six months and was calibrated in September 2008 in preparation for integration onto the NPP. Figure 2 is a drawing of the CERES instrument. The FM-5 will be mounted on a 12-cm pedestal on NPP to provide an unobstructed field of view for cross-track scanning, including the space view necessary for the detectors. The spacecraft will not provide an unobstructed 360^{o} field of view, thus the instrument will not be used to collect bidirectional reflectance information. The design parameters of the CERES instrument which affect the spacecraft are listed in Table 1.

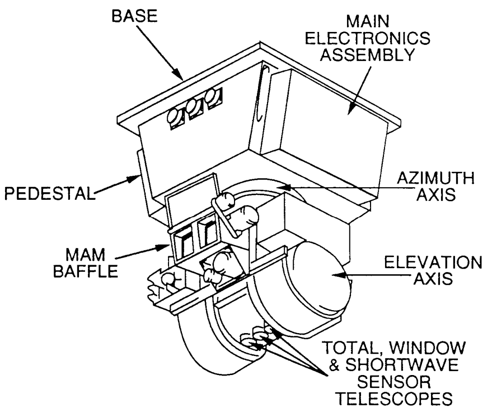

Figure 2: CERES instrument

Table 1. CERES parameters for Spacecraft

Height	63.5 cm
Diameter	60.2 cm
Power	50 W
Data rate	< 11 kbps
Pointing:	
Accuracy	12 arcmin
knowledge	2 arcmin
Stability	84 arcsec/6.6 sec

Figure 3 is a side view of the NPP and fig. 4 shows the Earth facing side of the spacecraft. The mission of the NPOESS Preparatory Project (NPP) is to demonstrate advanced technology for atmospheric sounding, giving continuing observations about global change after EOS-PM (Terra) and EOS-AM (Aqua). It supplies data on atmospheric and sea surface temperatures,

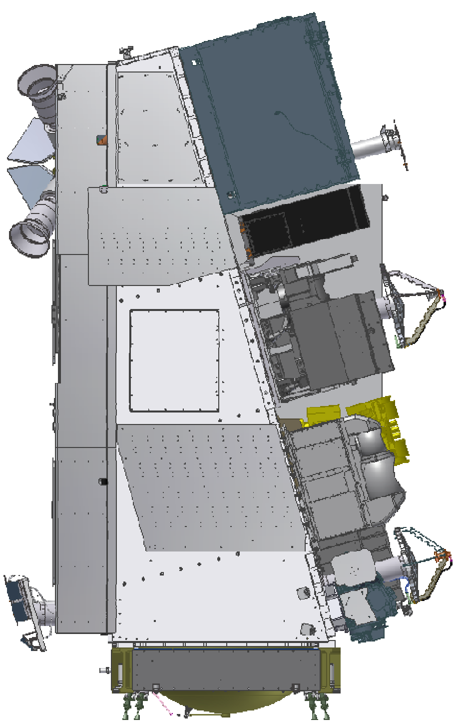

Figure 3: Side view of NPOESS Preparatory spacecraft (NPP)

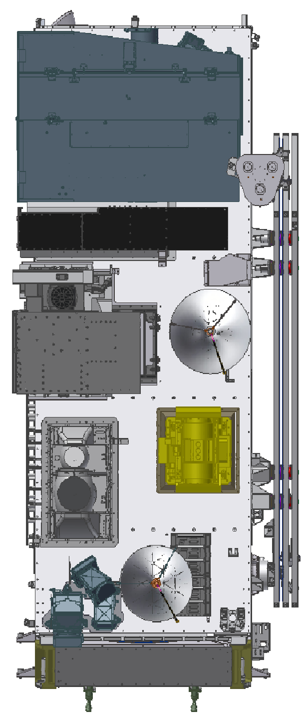

Figure 4: Earth facing side of NPP. CERES FM-5 is on right-hand side of spacecraft between two conical antennae.

humidity soundings, land and ocean biological productivity, and cloud and aerosol properties. In addition to CERES FM-5, the NPP spacecraft carries the Visible Infrared Imaging spectro-Radiometer Suite (VIIRS), which is similar to the MODIS but with fewer channels and will provide cloud data for the analysis of the CERES data. The instrument complement also includes the Cross-track Infrared Sounder (CrIS), the Advanced Technology Microwave Sounder (ATMS) and the Ozone Mapping and Profiler Suite (OMPS).

CERES FM-5 instrument is between the two conical antennae. CERES will operate nearly continuously in cross-track mode from one limb of the Earth to the other to map the Earth's radiation fields. The scan cycle is 6.6 seconds for all modes. The Sun will be used with the Mirror Attenuator Mosaic as a calibration source on a biweekly basis. A small rotation in azimuth will be required to get the line of sight to the Sun, but the 360^o biaxial scan capability is not planned for use on NPP, thus there was no attempt to make an unobstructed field-of-view available in all directions. To avoid contamination during launch, the scan head will be rotated 180 from nadir to so that the detectors are inside the instrument, and will be deployed after a month so that the spacecraft can complete ouitgassing.

Only minor changes to FM-5 and the NPP host spacecraft were required, as the NPP was originally designed to carry a CERES instrument. The instrument operations, data processing and data products are a continuation of those for the CERES instruments aboard the Terra and Aqua spacecraft. The instrument is thermally independent of the spacecraft and radiator surface must be added to the instrument. The NPP orbit is higher than the Terra and Aqua orbit, so the scan tables will be modified. The radiation environment was reviewed to make certain that the electronics would not be jeopardized at this altitude. The instrument had to be delivered for integration to the spacecraft by 15 November 2008 for the FY-10 launch, resulting in a tight schedule for CERES.

4. COMPARISON OF FM-5 RADIANCES WITH OTHER RADIOMETERS

For the FM-5 data to join seamlessly with the earlier measurements to continue the Earth Radiation Budget Climate Data Record, it is necessary to have the overlap of several months with the predecessor and with the successor. Hopefully the FM-1 and FM-2 aboard the Terra spacecraft and the FM-4 aboard the Aqua will still be operating as predecessors. During the first few months after the FM-5 begins to operate in orbit, data should be collected such that the radiances of the FM-5 and the other instrument can be compared directly, i.e. the same scene is observed from the same direction.

When comparing measurements from radiation budget instruments, if the scene is not viewed from the same direction, it is necessary to use a model to account for the anisotropy of the outgoing radiation, which results in errors in the comparison. If possible, one operates the instruments so as to align the instruments to measure the same scene from the same direction at the same time, with a small window in time and direction.

The NPP and the Aqua spacecraft will both be in Sun-synchronous orbits which cross the Equator northbound at 1330 hours. Aqua has an orbit altitude of 705 km and the altitude of the orbit of NPP will be 824 km. The orbits will be very-nearly co-planar. The orbit period of Aqua is less than that of NPP, so that the Aqua will overtake the NPP periodically. During the underpass, the Aqua will scan the same scenes as does the NPP, and near nadir the directions of the radiances will be close while operating in cross-track scan. These measurements will match for the scenes and within the acceptable window for the time and direction for a short portion of the orbit, thereby giving the overlap data for connecting FM-5 to FM-4.

To compare FM-5 radiance measurements with those from FM-1 or FM-2 aboard Terra, The NPP and Terra orbits will intersect at 70^oN at noon and at 70^oS at midnight. The method developed by Szewczyk et al. (2005) will be used for this comparison, whereby the instruments are rotated to scan in the east-west plane in order to align the directions. These operations are conducted near the northern summer solstice so as to maximize the reflected shortwave radiances at 70^oN to compare the shortwave channel and the shortwave part of the total channels of the instruments. At 70^oS the longwave responses of the total channel and the window channels can be compared. Because of the greater altitude of NPP, only the measurements near nadir will match within the direction window and will be used. If science requirements demand that the FM-5 continue to scan cross-track, the method can be modified to rotate the FM-1 or FM-2 in azimuth to align with the scan plane of the FM-5 as the orbits cross. The successor instrument to FM-5 for the Earth Radiation Budget Climate Record will be the CERES FM-6 instrument, which is planned to fly on the first NPOESS

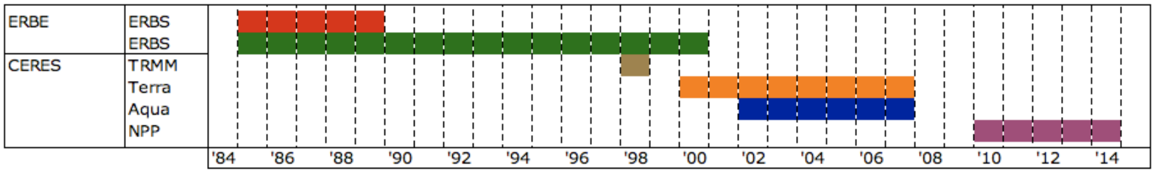

Figure 5: Time line of Radiation budget data

spacecraft. The orbit of the NPOESS-1 is currently the same as NPP.

GERB instruments are operating aboard the MeteoSat geostationary satellites (Harries et al., 2004) and are scheduled to be functioning until at least 2020. Radiance comparisons can be made with FM-5 as described by Smith et al. (2003)

France and India are collaborating to fly the ScaRaB-3 (SCAnner for RAdiation Budget) instrument aboard the Megha-Tropique spacecraft, which will use a precessing orbit of 22^o inclination. The NPP and Megha-Tropique orbits will intersect between 22 ^{o}S and 22^oN between 1300 and 1400 hours local time during day and between 0100 and 0200 hours during night. The same method (Haeffelin et al., 2001) can be used to compare radiances for these two spacecraft as for the CERES instruments aboard the Terra and TRMM spacecraft.

5. CERES FM-6 ON NPOESS C1

In 2013 the NPOESS spacecraft is scheduled to become operational with an Earth radiation budget instrument, which will be the successor of the FM-5. Enough spare parts were produced or purchased to build another copy of CERES, the FM-6, for flight on the NPOESS C1 platform in 2013. Evolution of technology provides enhanced capabilities, e.g. in the detector manufacture and in ground calibration which has surpassed that for CERES. The fabrication of the Mirror Attenuator Mosaic has significantly improved. This is an ideal opportunity to use state of the art measurement and engineering capabilities to meet the more demanding science requirements, while providing performance with better costs. The FM-6 will incorporate modest improvements over the first CERES instruments; these include improved Mirror Attenuated Mosaic, Shortwave Incandescent Calibration Source and ground calibration. This work is now ongoing.

6. CERES FOLLOW-ON FOR NPOESS C3

For the NPOESS C3, to be launched in 2018, and future missions, a new version of CERES will be designed and built. The present CERES was designed in the early 1990's with 1980's technology and many of the key components, such as processors, RAM or the detectors, are no longer available or feasible to produce. Thus, building another CERES is not a viable option. Initial concepts for the CERES follow-on instrument has now started for use on the NPOESS C3 platform and for future missions.

The option of designing and building a CERES follow-on instrument for flight on the NPOESS C1 platform was considered. This would give the improved instrument sooner. However, the time constraint for a 2013 launch would limit the options in case of any schedule slips in the CERES II delivery, which could force acceptance of an instrument design which is not as good as desired, not only for the C1 but for the next two decades

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