CERES: The Next Generation of Earth Radiation Budget Measurements

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ABSTRACT

NASA's Earth Observing System (EOS) is part of an international program for studying the Earth from space using a multiple-instrument, multiple-satellite approach. The Clouds and the Earth's Radiant Energy System (CERES) experiment is designed to monitor changes in the Earth's radiant energy system and cloud systems and to provide these data with sufficient simultaneity and accuracy to examine critical cloud/climate feedback mechanisms which may play a major role in determining future changes in the climate system. The first EOS satellite (Terra), scheduled for launch this year, and the EOS-PM satellite, to be launched in late 2000, will each carry two CERES instruments. The first CERES instrument was launched in 1997 on the Tropical Rainfall Measuring Mission (TRMM) satellite. The CERES TRMM data show excellent instrument stability and a factor of 2 to 3 less error than previous Earth radiation budget missions. The first CERES data products have been validated and archived. The data consist of instantaneous longwave and shortwave broadband radiances, top-of-atmosphere fluxes, scene types, and time and space averaged fluxes and albedo. A later data product will combine CERES radiances and high-resolution imager data to produce cloud properties and fluxes throughout the atmosphere and at the surface.

Keywords: radiation, clouds, climate change

1. INTRODUCTION

For centuries, mankind has engaged in activities that alter the environment and, potentially, the global climate. Fossil fuel burning and release of other trace gases and aerosols may well have significant long-term consequences. Since 1800, atmospheric carbon dioxide has increased by 25% and methane concentrations have more than doubled. Agriculture and deforestation alter the Earth's surface in ways that have the potential to change the climate. In these and many other examples, the immediate impacts of man's activities are understood, yet the long-term consequences on the Earth-atmosphere system cannot easily be predicted. For example, one of the major sources of uncertainty in predicting climate change lies in the impact of clouds upon the radiative energy flow through the Earth-atmosphere system. The largest uncertainty in climate prediction models is how to correctly account for the effects of clouds. Because of the importance and uncertainties of clouds and radiation fields, they have become one of the top scientific priorities in the U. S. Global Change Research Program.

As the Earth undergoes changes in its climate, the amount of cloud cover as well as the physical properties of clouds may change in ways that are not yet understood. The complex interaction between a changing climate system and the changing cloud conditions is called cloud-climate "feedback." Do clouds decrease or increase global warming? Will a warmer climate result in fewer or more clouds? Can a "runaway greenhouse effect" occur as it did on the planet Venus? While we cannot as yet provide definite answers to such questions, climate model sensitivity studies have indicated that relatively small changes in global cloudiness can have a large impact on our climate system. For example, a 50% increase in carbon dioxide may warm the Earth much less than a 50% increase in the amount of high cirrus clouds. The Clouds and the Earth's Radiant Energy System (CERES[1]) experiment is the next generation of satellite instrument designed to monitor changes in the Earth's radiant energy system and cloud systems for climate studies.

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2. EOS and CERES

NASA's Earth Observing System (EOS) program is critical for providing a scientific understanding of ongoing natural and human-induced global climate change and providing a sound scientific basis for developing global environmental policies[2]. The CERES experiment is one of the highest priority scientific satellite instruments developed for EOS. CERES will measure both solar-reflected and Earth-emitted radiation from the top of the atmosphere to the Earth's surface. It will also determine cloud properties including the amount, height, thickness, particle size, and phase of clouds using simultaneous measurements by other EOS instruments such as the Moderate Resolution Imaging Spectroradiometer (MODIS). Analyses of these data, building on the foundation laid by previous missions such as the Earth Radiation Budget Experiment (ERBE[3]), will lead to a better understanding of the role of clouds and the energy cycle in global climate change.

The first EOS satellite, Terra, will be launched this year and will carry two CERES instruments. CERES instruments will also fly on the EOS PM-1 mission scheduled for launch in late 2000 to provide continued atmospheric monitoring and a long-term climate data set. Multiple satellites are needed to provide adequate temporal sampling as clouds and radiative fluxes vary throughout the day.

3. CERES INSTRUMENTS

The CERES instrument (figure 1) is based on the successful ERBE scanning radiometer design with several improvements to accommodate upgraded performance requirements and hardware developments. CERES has twice the spatial resolution and improved instrument calibration. The two EOS spacecrafts will each carry two identical instruments: one will operate in a cross-track scan mode and the other in a biaxial scan mode. The cross-track scan will essentially continue the measurements of the ERBE, while the biaxial scan mode will provide new angular flux information that will improve the accuracy of angular models used to convert broadband radiance to flux. Each CERES instrument has three channels—a shortwave channel to measure reflected sunlight, a longwave (LW) channel to measure Earth-emitted thermal radiation in the 8-12 μm "window" region, and a total channel to measure all wavelengths of radiation. Onboard calibration sources include a solar diffuser, a tungsten lamp system with a stability monitor, and a pair of blackbodies that can be controlled at different temperatures. Cold space-looks and internal calibrations are performed during normal Earth scans. The CERES instrument is managed by the NASA Langley Research Center in Hampton, Virginia, and built by TRW's Space and Technology Group in Redondo Beach, CA.

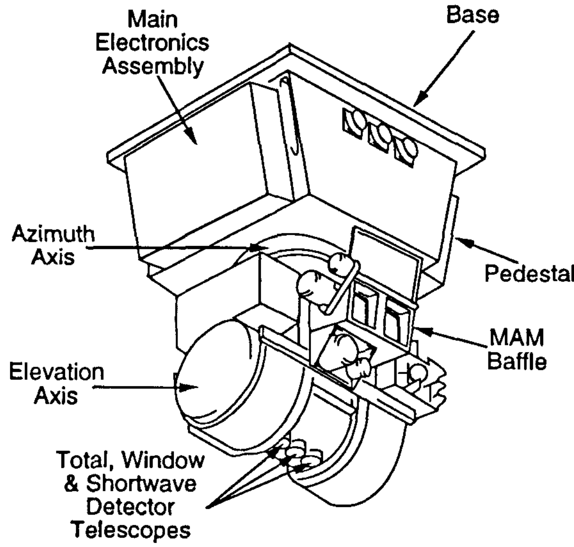

Figure 1. The CERES instrument.

4. CERES DATA PRODUCTS

A key element in the success of CERES, beyond the development of an instrument, is the development of data analysis and interpretation techniques for producing radiation and cloud products which meet the scientific objectives of the project. This data analysis yields three major types of archival products: ERBE-like, Top-of-Atmosphere (TOA) and Surface, and Atmosphere Products. The CERES data processing flow is shown in figure 2. The CERES data product descriptions are given in the Data Products Catalog which can be accessed on the web at http://asd-www.larc.nasa.gov/DPC/DPC.html.

ERBE-like Products are processed with the ERBE algorithms and are as identical as possible to those produced by the previous generation ERBE instruments. These products include monthly average TOA broadband shortwave, longwave, and net radiative fluxes for both cloudy sky and clear sky conditions.

TOA and Surface Products use co-located cloud imager data for scene classification and CERES measurements to provide radiative fluxes for both cloudy and clear sky conditions. Surface radiation budget estimates are based on direct observational relationships between top-of-atmosphere and surface fluxes. TOA and Surface Products are used for studies of land and ocean surface energy budget, as well as climate studies that require high accuracy fluxes. Atmosphere Products use cloud physical properties, temperature, water vapor, ozone and aerosol data, and a broadband radiative transfer model to compute estimates of shortwave and longwave radiative fluxes at the surface, at levels within the atmosphere, and at the top of the atmosphere. The CERES TOA radiative fluxes are the "truth" reference used to constrain the theoretical calculations. Atmosphere products are designed for studies of energy balance within the atmosphere, as well as climate studies that require consistent cloud, TOA, and surface radiation data sets.

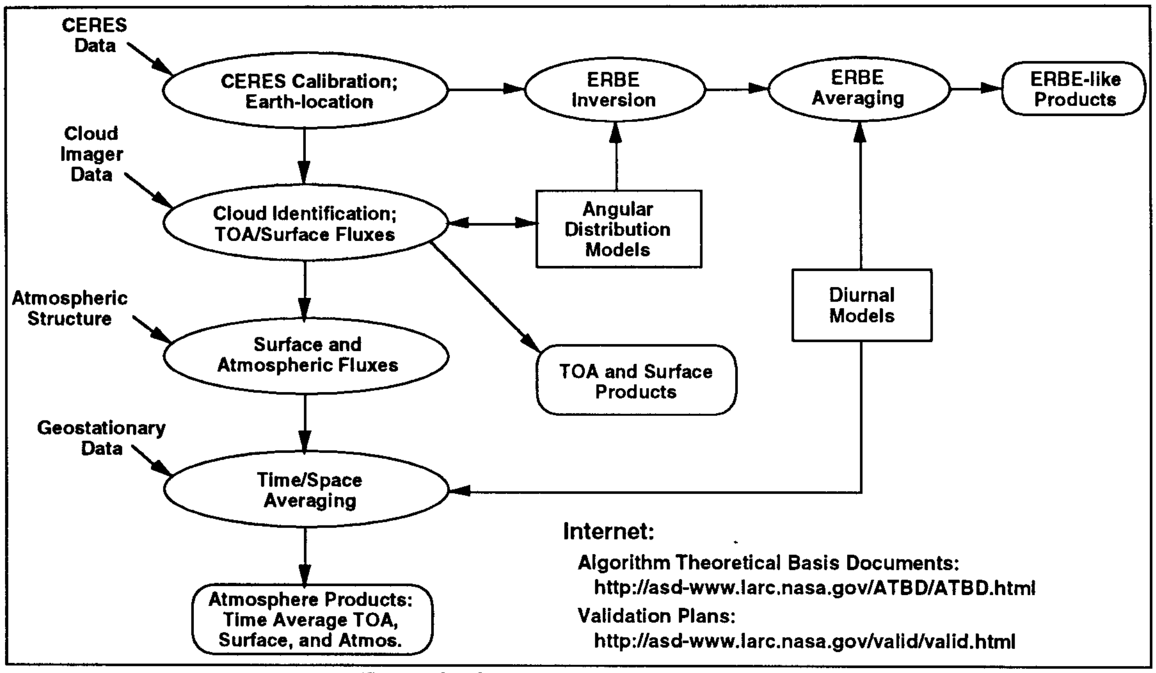

Figure 2. CERES Data Processing Flow

5. CERES ON TRMM---EARLY RESULTS

The first CERES radiometer was launched in November 1997 on the Tropical Rainfall Measuring Mission (TRMM) satellite and has produced 8 months of high-quality data. The initial data from CERES already suggest that the CERES instruments are substantially improved over the ERBE instruments[4]. The CERES instrument has shown remarkable stability. There has been no discernable change in instrument gain for any channel at the 0.2% level with 95% confidence. Ground and in-space calibrations agree to within 0.25%. CERES is providing radiative fluxes with a factor of 2 to 3 less error than the ERBE data. The validated CERES ERBE-Like data are available at: eosweb.larc.nasa.gov/project/ceres/table_ceres.html.

Two early CERES results have been of particular interest. First, the CERES rotating azimuth plane data were used by Hu et al. (1999)[5] to develop new anisotropic models for deep convective clouds with infrared window brightness temperatures less than 205K. The broadband shortwave anisotropy of these deep convective clouds was found to be the most Lambertian and least variable of any surface or cloud observed to date. Using the new anisotropic functions, deep convective cloud albedos were determined for all CERES fields of view in January through March 1998 with solar zenith angles between 38 and 43 degrees. Mean albedo for these clouds was 0.74, substantially less than the 0.80 maximum albedo expected from theory in the optically thick limit with a particle radius of 30 μm. Two possible explanations for the lower than expected albedo of these deep convective clouds include 3-D inhomogeneities and optical thicknesses

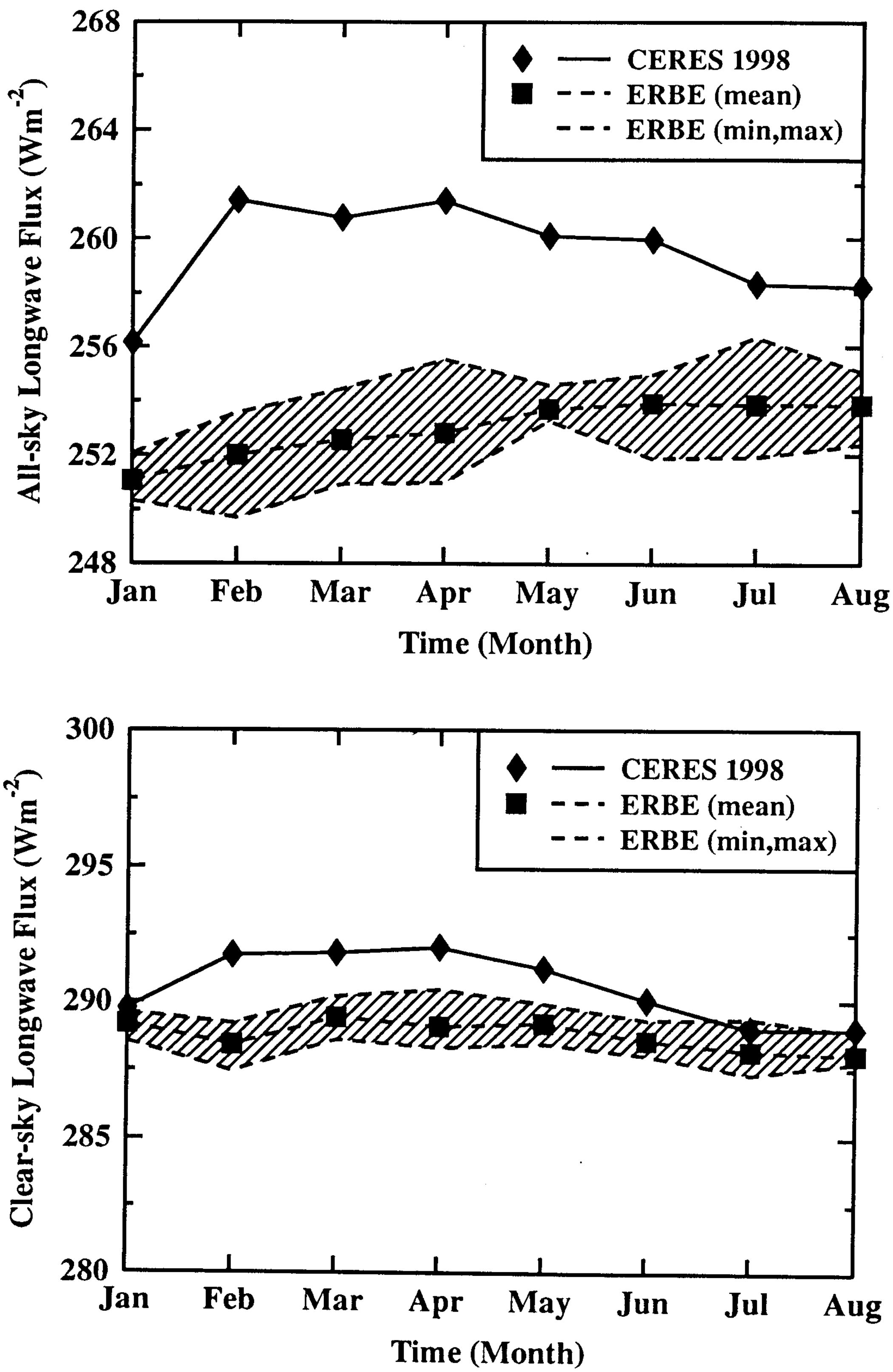

Figure 3. Tropical mean monthly average longwave flux for CERES (1998) and ERBE (1985-89) for all-sky (top) and clear-sky (bottom).

low enough to allow substantial transmission to the surface. Neither of these explanations, however, seems consistent with the remarkably low variability in deep convective albedo for the precipitating clouds.

The second early CERES result of interest is the surprising differences in tropical mean (20S to 20N latitude) LW fluxes between CERES in 1998 and the ERBE scanner climatology for 1985-1989 (Wielicki et al. 1999)[6]. Figure 3 (top) shows tropical mean LW fluxes measured by the CERES scanner in January through August of 1998 compared to the ERBE scanner climatology for the same months in 1985-1989. The shaded area in the figure shows the total range measured by the 5 years of ERBE data for each month.

Two things are evident in this figure. First, there is a large change relative to ERBE between the peak of the 1998 ENSO event in February 1998 and the end of the El Nino phase in July/August of 1998. The anomaly drops from 9 Wm^{-2} in February to 4.5 Wm^{-2} in July/August. Second, even after the ENSO event has subsided in July there remains a 4.5 Wm^{-2} difference in tropical mean LW flux between CERES and ERBE. In order to understand this difference, Wong et al. (1999)[7] compared the CERES and ERBE clear-sky LW tropical mean fluxes (bottom of figure 3). They found excellent agreement in July and August of 1998 (within about 0.5 Wm^{-2}) and anomalies in other months of 1998 of up to 2 Wm^{-2} which were in agreement with the ENSO changes in temperatures and water vapor in the tropics. Further consistency checks of the CERES absolute calibration using deep convective clouds and comparing all three CERES channels (window, total, shortwave) concluded that 1 Wm^{-2} of the CERES/ERBE difference could be explained by a roughly 1% inconsistency in the three channels (Kratz et al. 1999)[8]. This leaves 3.5 Wm^{-2} unexplained at the present time.

The ERBS Wide-Field-of-View (WFOV) active cavity radiometers have operated from 1984 through 1999, allowing a consistent overlapping broadband measurement to compare ERBE and CERES records. The ERBS WFOV tropical mean LW flux anomalies for each month in 1998 agree with the CERES scanner to within 1 Wm^{-2}. Both data sets show the large ENSO signal in February, 1998 as well as the remaining difference in July/August of 1998. While these results are too preliminary to be considered conclusive at this time, they suggest a significant change in the tropics between the late 1990s and 1980s. The agreement between ERBE and CERES clear-sky fluxes indicates that the changes in all-sky fluxes are caused by changes in cloud properties.

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