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ERBE AND CERES BROADBAND SCANNING RADIOMETERS

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INTRODUCTION

Broadband scanning radiometers have been used extensively on Earth-orbiting satellites to measure the Earth's outgoing radiation. The resulting estimates of longwave and shortwave fluxes have played an important role in helping to understand the Earth's radiant energy balance or budget. The Clouds and the Earth's Radiant Energy System (CERES) experiment is expected to include instruments with three broadband scanning radiometers. The design of the CERES instrument will draw heavily from the flight-proven Earth Radiation Budget Experiment (ERBE) scanner instrument technology and will benefit from the several years of ERBE experience in mission operations and data processing. The discussion in this paper starts with a description of the scientific objectives of ERBE and CERES. Next follows comparisons between the design and operational characteristics of the ERBE and CERES instruments and between the two ground-based data processing systems. Finally, aspects of the CERES data processing which might be performed in near real-time aboard a spacecraft platform are discussed, and the types of algorithms and input data requirements for the on-board processing system are identified.

SCIENTIFIC OBJECTIVES AND EARTH SATELLITE SYSTEMS OF ERBE AND CERES

The scientific objectives of the ERBE mission are listed in table 1, and these objectives and the overall ERBE mission concept are described in reference 1. ERBE scanner instruments are flying on three Earth-orbiting spacecraft, the ERBS, NOAA-9, and NOAA-10. The ERBS spacecraft and its on-board ERBE instruments are operated by NASA from the Goddard Space Flight Center, Greenbelt, Maryland; and the NOAA-9 and NOAA-10 TIROS weather satellites are operated by NOAA from Suitland, Maryland. ERBS is in a processing orbit with an inclination of 57° while NOAA-9 and NOAA-10 are in near-polar, Sun-synchronous orbits with different local times for their ascending nodes. ERBS and NOAA-9 have been operating since October and December 1984, respectively, and NOAA-10 has been operating since September 1986.

The CERES mission is expected to meet the scientific objectives of ERBE but also incorporates additional scientific objectives (see table 2). The satellite system currently being proposed for the Earth Observing System (Eos) is similar to that of ERBE and consists of the Space Station Freedom platform in a low-inclination processing orbit and the NASA and European Space Agency (ESA) platforms in near-polar, Sun-synchronous orbits.

DESIGN AND OPERATION OF THE ERBE AND CERES INSTRUMENTS

Figure 1 is a schematic of the ERBE scanner instrument, and table 3 lists some of the ERBE instrument's important design characteristics. Further details on the design of the ERBE scanner instrument can be found in reference 2. Two identical CERES instruments are proposed to be flown on each of the orbiting Eos platforms. Figure 2 is a drawing of the proposed CERES instrument, and table 4 lists preliminary design characteristics of the CERES instrument for comparison with those of ERBE. The ERBE and CERES instruments are controlled by their own microprocessors. Thus, each instrument can be directed to change its operational mode by sending real-time commands or by storing commands in the spacecraft computer memory for execution at specified times.

The most significant difference between the ERBE instrument and the proposed CERES instrument is the operation of the azimuth beam, which controls the plane in which the detectors scan. The entire instrument structure below the pedestal of both instruments (see figures 1 and 2) can rotate in azimuth between 0 and 180°. The ERBE instrument normally operates in a fixed cross-track position (azimuth = 0 or 180°), and the azimuth beam is rotated to the Sun azimuth only for solar calibrations or other special events. Both CERES instruments aboard a platform will be designed to rotate continually in azimuth between 0 and 180°. It is expected, however, that one of the CERES instruments will normally operate in the fixed cross-track mode to provide maximum spatial coverage and to provide continuity with measurements from the ERBE scanner instruments. The second CERES instrument will operate in the rotating-azimuth mode. The rotating-azimuth mode of operation will provide better angular sampling for improved Angular Distribution Model (ADM) development and reduction of flux errors from the ADM's.

The ERBE instrument can operate in four different scan modes. The scan modes include three Earth-viewing modes and a solar scan mode (used during solar calibrations). The CERES instrument is expected to have the same scan-mode capability. The instrument output in any of the four scan modes consists of 74 radiometric measurements per channel during a 4-second scan period. In the normal Earth scan mode, 8 measurements are made as the detectors view space 14° below the horizon (space look); 62 measurements are made as the detectors scan the Earth from horizon to horizon; and the final 4 measurements are made as the detectors view the internal calibration sources at a scan position inside the instrument housing on the opposite side of the instrument from the space look. The sampling rate for all measurements is 0.033 seconds. In the solar scan mode, the detectors view space and then scan directly to a position in the instrument housing where they view the attenuated output of the Sun which is incident on the two side-by-side apertures shown in the drawings of figures 1 and 2.

Two types of calibrations can be performed with the ERBE instruments: internal and solar. The CERES instrument calibration options are expected to be the same as those of ERBE. Both calibrations are performed using special preprogrammed sequences of microprocessor commands. Internal calibrations are performed while the instrument remains in the normal Earth-scan mode. The solar calibration sequence includes commands which rotate the azimuth beam to the required Sun azimuth angle and cause the instrument to change to the solar scan mode.

The field stop in front of the ERBE detectors is a 3.0°- × 4.5°-hexagonal aperture, chosen to offset aliasing effects caused by scan motion and data sampling rates. The design technology of the CERES radiometric detectors will be very similar to that of ERBE. To reduce the field of view of the CERES detectors significantly from that of ERBE would probably require changing to another type of detector technology. Comparing tables 2 and 3 shows that the currently proposed spectral characteristics of the three CERES radiometric detectors differ slightly from those of the ERBE detectors. Although the filters which will be used on CERES will be an improvement over those on ERBE, they will not be perfect filters. Some spectral corrections will still need to be made to the raw radiometric measurements.

The relatively low ERBE instrument data rate of 960 bits per second includes the radiometric measurements and instrument housekeeping measurements. The total ERBE instrument output during a 4-second scan period consists of 74 radiometric measurements for each channel, the corresponding elevation or scan angle, and 24 housekeeping measurements. The output of the CERES instruments will need, in addition to these data, azimuth position data corresponding to each of the 74 radiometric measurements. The total data output of a CERES instrument will, therefore, be moderately higher than that of ERBE.

GROUND-BASED DATA PROCESSING

The ERBE telemetry data which are provided to Langley by Goddard and NOAA consist of the entire raw output of the ERBE instruments and certain spacecraft housekeeping data. Goddard computes and provides the ephemeris data for all three spacecraft. A flow chart of the ERBE data processing system is shown in figure 3. The ground-based data processing system for CERES is expected to be an extension of the ERBE data processing system.

The circles in figure 3 represent processing tasks, and the rectangles represent algorithms or data input (arrows drawn into circles) or data output (arrows drawn out of circles). The processing down to the Merge circle (step 4.1) consists mostly of decommutation, screening and editing, and reformatting of the data. In the next two processing steps (steps 4.1 and 4.2), the telemetry and ephemeris data are merged, and the locations of the measurements on the Earth's surface are computed. The data products at this point (Earth-located raw measurements) are archived by the ERBE project at the National Space Sciences Data Center (NSSDC). This archival data product is called the Raw Archival Tape or the RAT. In the next step, the raw radiometric measurements are converted to radiances, using algorithms and calibration data obtained from preflight testing and in-flight calibrations. The conversion algorithms also make use of certain instrument housekeeping measurements. The converted radiances are edited before they are corrected spectrally and inverted to the top of the Earth's atmosphere (TOA). The raw radiance measurements are corrected for errors caused by spectral filtering using scene identification information derived from the measurements themselves. The corrected radiances (sometimes called inveterate radiances) are then inverted to radiant fluxes at the TOA using input angular models which have been derived from data obtained on previous missions. The models used on ERBE were derived from data obtained from NIMBUS 7.

The instantaneous longwave and shortwave fluxes at the top of the Earth's atmosphere represent the lowest level Earth radiation budget data useful in scientific investigations. The ERBE data product which includes the instantaneous fluxes is called the Processed Archival Tape (PAT) and is archived on 24-hour tapes by the ERBE project at the NSSDC. The corresponding data from CERES will be called the Standard Data Product and will also be archived. These data can be useful in a host of studies in which an investigator might want to perform his own spatial and temporal averaging. The instantaneous fluxes would also likely be the most useful data in real-time applications, and so the remaining discussion will focus on the processing required to produce this data product and the types of algorithms and input data required.

ON-BOARD PROCESSING REQUIREMENTS

Figure 4 is a simplified flow chart of the processing steps required to produce the instantaneous fluxes at the top of the Earth's atmosphere. The input telemetry data are assumed to include the output of the CERES instruments and all spacecraft data required, such as operational mode and attitude data. The ephemeris data are assumed to be available from on-board sources and to include accurate spacecraft and solar ephemeris data. Each bullet in figure 4 can be thought of as a process that requires a set of algorithms and/or data input. The lines marked with stars identify algorithms and/or data which are subject to changes during the mission.

Decommutation of the telemetry data and reformatting of the telemetry and ephemeris data are required before the two data streams can be merged. The on-board data screening algorithms could, perhaps, be simpler than those used in the ground-based processing system, but ERBE experience taught us that quality evaluation of the data is very important. Merging the telemetry and ephemeris data and computing the Earth locations of the measurements may be straightforward but require moderate numbers of vector transformations. The Earth location computations could be simplified by modeling the motions of the instruments azimuth and elevation beams, but such a modeling procedure would increase the risk of mislocating some of the measurements.

Algorithms for conversion of the housekeeping and radiometric data will require raw sensor output as well as other housekeeping measurements. Calibration coefficients used in the algorithms to convert the raw radiometric measurements to radiances will probably need to be updated with results from in-flight instrument calibration data. ERBE experience taught us that editing of the converted radiometric and housekeeping measurements increases the confidence level of the resulting science products; some editing algorithms would be desirable at this point in the processing.

Correcting the converted radiances for errors in spectral filtering can be done using stored correction factors whose values are a function of the specific scene over which the measurement is made. The radiances used to produce the CERES Standard Data Product will be corrected using scene identification information derived from the CERES measurements. An on-board processing system could probably improve the scene identification process by making use of the data output from other on-board instruments, such as MODIS.

The final step in the process to produce the CERES Standard Data Product is inversion of the corrected longwave and shortwave radiances to radiant fluxes at the top of the Earth's atmosphere. The primary data contained in the CERES Standard Data Product, which include the instantaneous radiances, shortwave and longwave fluxes, and the associated scene, are listed in table 5. In the inversion process, angular models of the Earth's radiant energy are applied to each radiance measurement to produce a value of the radiation field at a point on a reference surface above the Earth. The angular radiation models are usually stored in tables. The inversion of the longwave radiation component is relatively simple compared to that of the shortwave component, sometimes requiring no more than a limb darkening curve, which is a function of the measurement zenith angle relative to the instrument.

CONCLUDING REMARKS

The CERES mission is expected to incorporate essentially all the ERBE science objectives and will extend those objectives. The Eos Earth-satellite system is very similar to that of ERBE and consists of the low altitude, low inclination, processing orbit of the Space Station Freedom and the NASA and European Space Agency Sun-synchronous, polar-orbiting platforms. The CERES instrument design is expected to follow that of ERBE, but each CERES instrument package will consist of two scanners capable of rotating continuously in azimuth. One instrument is expected to operate in the fixed cross-track azimuth mode to provide maximum spatial coverage. The other instrument will operate in a biaxial (rotating-azimuth) mode to provide more complete angular sampling. The data rates for the CERES instrument, like those of ERBE, are very low.

The Standard Data Product of the CERES mission, which consists of the instantaneous radiant fluxes at the top of the Earth's atmosphere, will be produced by the ground-based Eos Dis system within 72 hours. The Standard Data Product, which could have near-real-time applications, might also be produced through processing aboard the Eos platforms. Some of the algorithms and data input required for the on-board processing may have to be scaled down to decrease the on-board processing burden.

REFERENCES

(1) - Barkstrom, Bruce R., 1984: "The Earth Radiation Budget Experiment (ERBE)." Bulletin of the American Meteorological Society.

(2) - Kopia, L. P., 1986: "The Earth Radiation Budget Experiment Scanner Instrument." Rev. Geophys. and Space Physics, 24, 400-406.

TABLE 1

SCIENTIFIC OBJECTIVES OF ERBE

Determine monthly averages of Earth radiation budget components at top of atmosphere for various spatial scales

- 250-km to 1000-km regions
- 10-degree latitudinal zones
- Global
- Equator-to-pole transport gradient

Determine average diurnal variations in the Earth radiation budget on a regional and monthly scale

TABLE 2

SCIENTIFIC OBJECTIVES OF CERES

Produce consistent global data base of radiation and clouds

- Use broadband scanner for radiation budget
- Use spectral information for clouds

Contribute to Eos tasks in

- Biogeochemical cycles
- Climatological processes
- Atmospheric geophysical processes
- Oceanic geophysical processes

Provide input for multidisciplinary approaches to

- $CO(2)$ induced climate changes
- El Nino-related weather perturbations

TABLE 3

ERBE SCANNER INSTRUMENT CHARACTERISTICS

COMPUTER-CONTROLLED OPERATIONAL MODES
- Any fixed azimuth position between 0 and 180° (normal crosstrack)

Four scan modes (3 Earth, 1 for solar calibration)
- Normal Earth scan - views space, Earth, internal calibration sources

Calibration sequences
- Internal - Views blackbodies, shortwave sources
- Solar - Views attenuated solar input

SPATIAL FIELD OF VIEW OF DETECTORS
- Approximately 3.5° circular aperture (Half power contour)

SPECTRAL CHARACTERISTICS OF DETECTORS

Total radiance	(0.2 to 50 microns)
Shortwave radiance	(0.2 to 5.0 microns)
Longwave radiance	(5.0 to 50 microns)

DATA RATES (EACH INSTRUMENT)
- 960 bits/sec (Radiometric and housekeeping data)
- 74 radiometric measurements per channel in 4-second scan cycle

TABLE 4

PRELIMINARY DESIGN CHARACTERISTICS OF CERES INSTRUMENT

TWO IDENTICAL INSTRUMENTS ON EACH ORBITING PLATFORM

COMPUTER-CONTROLLED OPERATION
- One instrument in fixed (crosstrack) azimuth position
- One instrument in rotating-azimuth mode (between 0 and 180°)

- Four scan modes (3 Earth, 1 for calibration)
  - Normal Earth scan - Views space, Earth, internal calibration sources

- Calibration sequences
  - Internal - Views blackbodies, shortwave sources
  - Solar - Views attenuated solar input

SPATIAL FIELD OF VIEW OF DETECTORS
- Approximately same as ERBE

SPECTRAL CHARACTERISTICS OF DETECTORS

Total radiance	(0.3 to 50.0 microns)
Shortwave radiance	(0.3 to 3.5 microns)
Longwave radiance	(5.0 to 50.0 microns)

DATA RATES (EACH INSTRUMENT)
- 2000 bits/sec (Radiometric and housekeeping data)
- Approximately 74 radiometric measurements per channel in 4-second scan cycle

TABLE 5

CONTENTS OF ERBE PROCESSED ARCHIVAL TAPE AND CERES STANDARD DATA PRODUCT

Times of measurements

Earth locations of measurements

Converted shortwave and longwave radiances (W/M**2.ST)

Derived shortwave and longwave top-of-atmosphere fluxes (W/M**2)

Scene identification (Clear, partly cloudy, mostly cloudy, overcast)

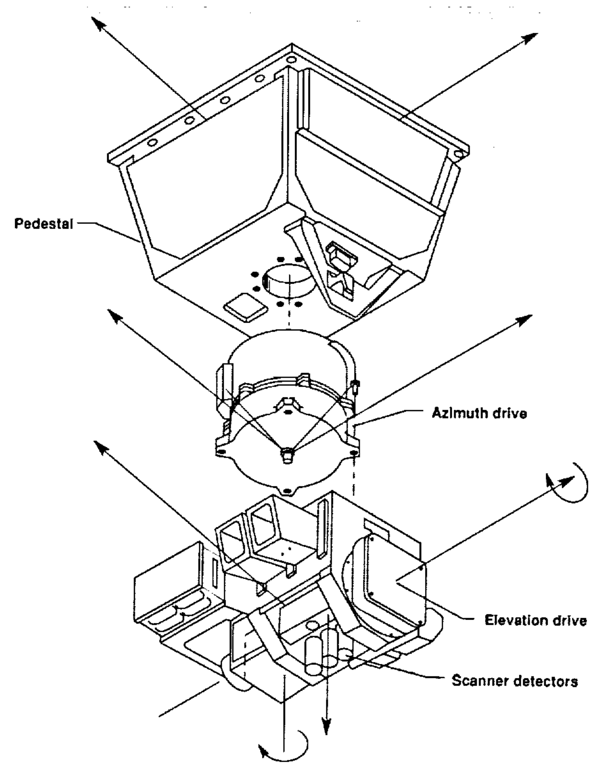

FIGURE 1.- ERBE SCANNER INSTRUMENT

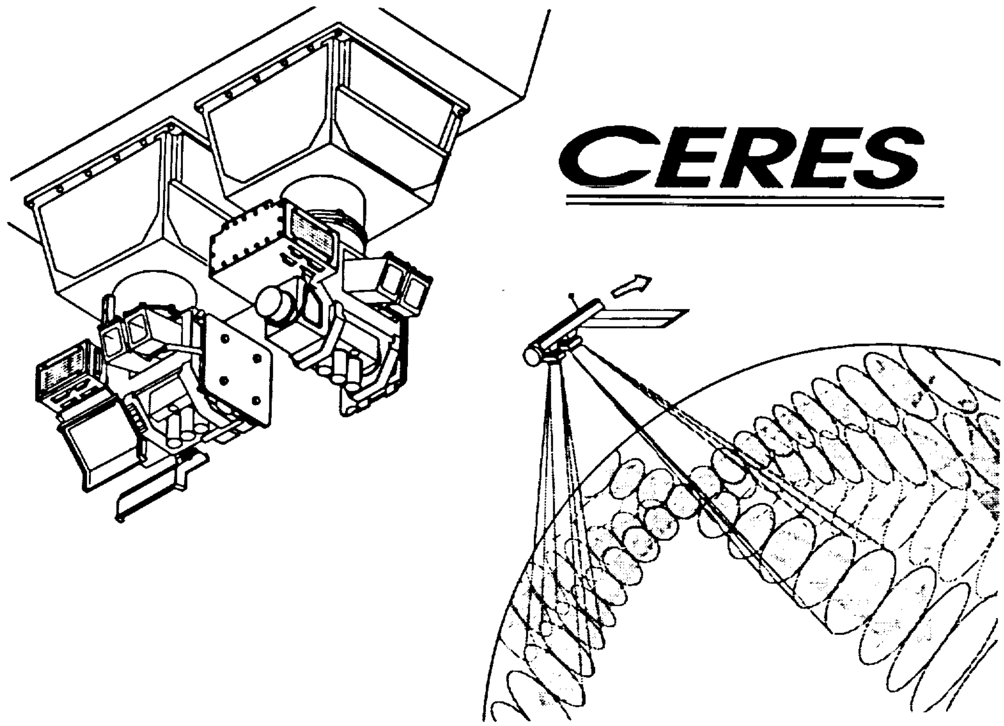

FIGURE 2.- CERES INSTRUMENT

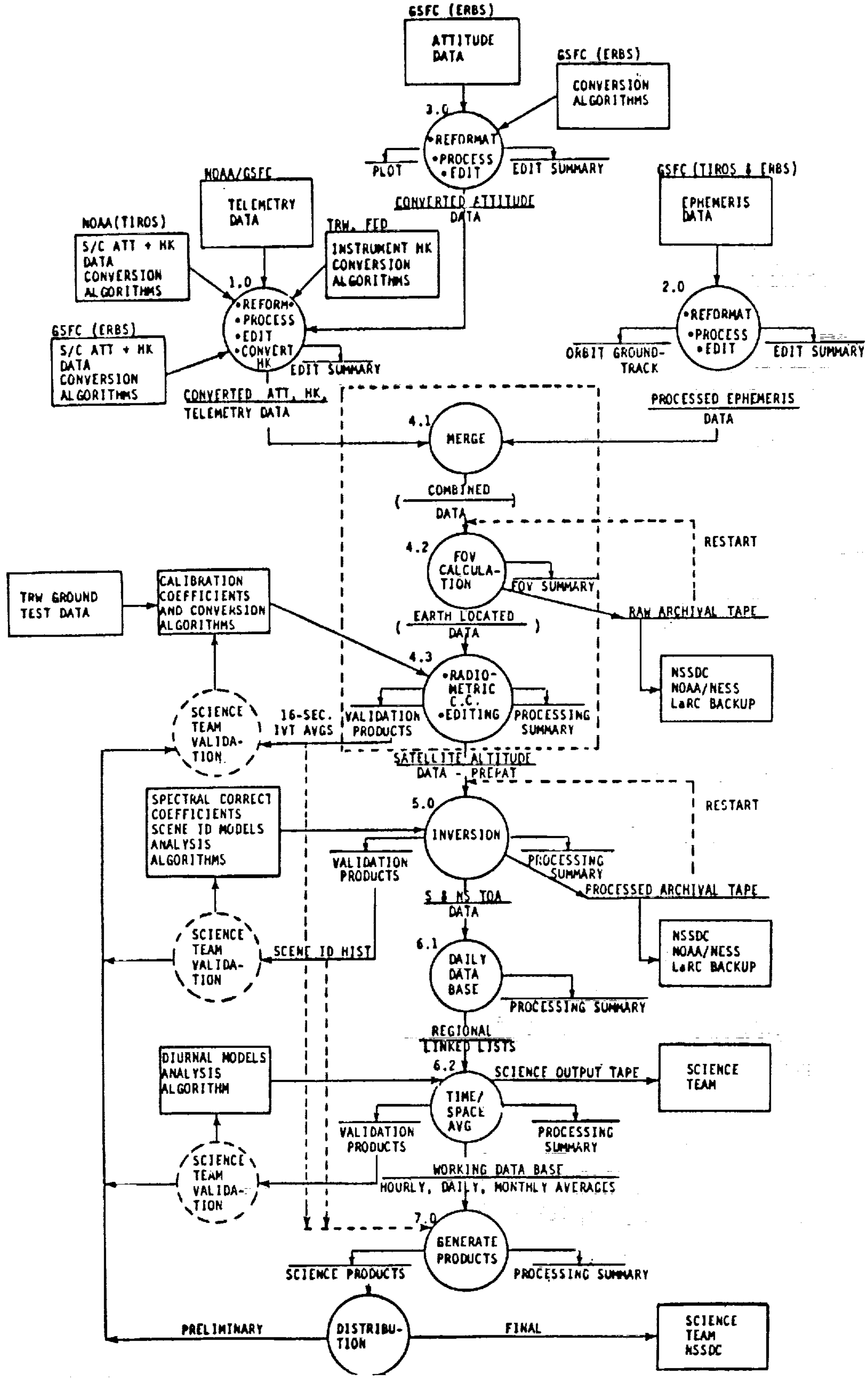

FIGURE 3.- ERBE GROUND-BASED DATA PROCESSING SYSTEM

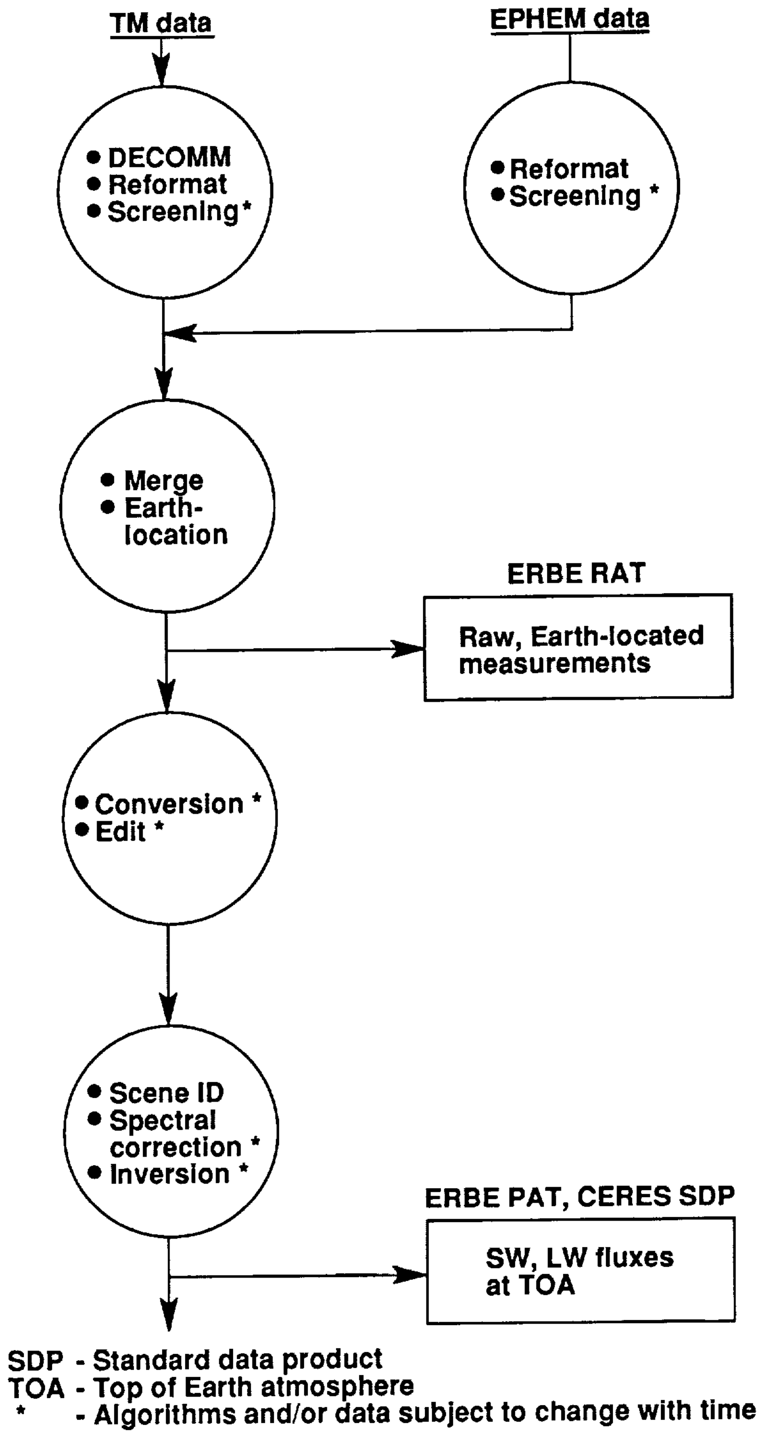

FIGURE 4.- PROCESSING TO PRODUCE RADIANT FLUXES AT TOP OF EARTH ATMOSPHERE