NOAA 9 Wide-field-of-View Radiometer Data Record

G. Louis Smith[1], Takmeng Wong[2] and Robert B. Lee, III[1]
1. National Institute of Aerospace; Hampton, Virginia
2. Langley Research Centre, NASA, Hampton, Virginia

ABSTRACT

An Earth Radiation Budget Experiment Wide-field-of-view radiometer aboard the NOAA 9 spacecraft provided measurements of radiation over the globe from February 1985 through December 1992. The shortwave channel, which measured reflected solar radiation, used a quartz dome as a filter. Long exposure to direct sunlight degraded the dome. The combination of NOAA 9 orbit geometry and sensor design resulted in degradation much greater on one side than the other, which affects the calibration, the measurements of solar radiation reflected by the Earth and the retrieval of albedo. These records were not suitable for archiving. This paper presents an analysis by which the measurements can be processed to generate a useful climate data record.

1. INTRODUCTION

The absorption of solar radiation by the Earth and the emission of this energy as longwave radiation govern the weather and climate of the Earth. The absorption and emission of radiation varies with location and time on many scales. In addition to the diurnal cycle and annual cycles of radiation, there is a variety of intraseasonal and interannual variations to be measured.

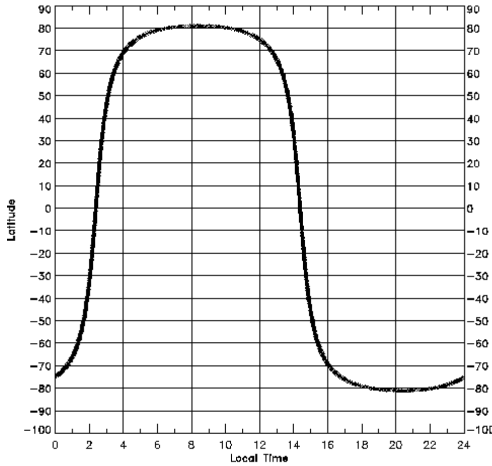
The Earth Radiation Budget Experiment (ERBE; Barkstrom and Smith, 1986) flew scanning and non-scanning wide-field-of-view (WFOV) radiometers aboard the NOAA 9 and NOAA 10 operational spacecraft and the dedicated Earth Radiation Budget Satellite (ERBS). These radiometers (Kopia, 1986; Luther, 1986) measured the solar radiation reflected by the Earth and the radiation emitted by the Earth. ERBE instruments on the two NOAA spacecraft gave data over the entire globe at four times of day to provide sampling of changes during the day (Harrison and Gibson, 19??). The ERBS was in an orbit with a 57^o inclination, precessing through all local times every 72 days, thus measuring the diurnal cycle. The WFOV radiometer aboard the NOAA 9 spacecraft provided measurements of radiation over the globe from February 1985 through December 1992, nearly eight years. The WFOV radiometers aboard ERBS operated for 15 years, covering the part of the globe between 57^{o}N and 57^{o}S.

Corresponding author: G. Louis Smith, g.l.smith@larc.nasa.gov; phone 1 757 864-5678; fax 1 757 864-6326; Mail Stop 420, Langley Research Centre, Hampton, Virginia, USA 23681.

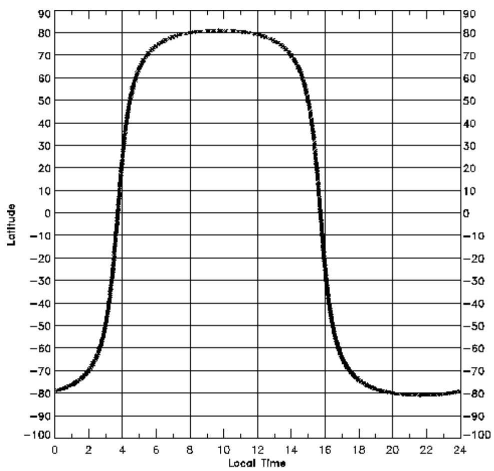
The NOAA 9 spacecraft was placed into an orbit which crossed the Equator at 1430 hours northbound. From this orbit, the instruments were able to observe most of the Earth in daylight and at night, as fig. 1a shows. The ERBE scanning radiometer operated for two years, providing a highly useful data set which covered the Earth during February 1985 through 1987.

Over a period of time the orbit precessed so that by mid-1988 its ascending node was at 1800 hours, so that as fig. 1b shows, much of its orbit was near the terminator. From this location the Earth is viewed at high solar zenith angles, so that the albedo and reflected solar radiation cannot be accurately retrieved. Furthermore, the diurnal sampling of the outgoing longwave radiation is very poor. There was also a problem with the nonscanning radiometers.

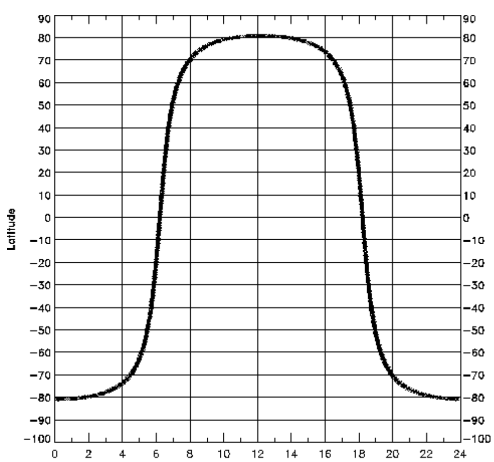
The shortwave channel of the WFOV radiometers, which measured reflected solar radiation, used a quartz dome as a filter to eliminate Earth-emitted radiation from entering the active cavity radiometer. Over long exposure to direct sunlight, the transmission of the dome to solar radiation degraded. The radiometer was periodically calibrated to take into account this degradation. The NOAA 9 orbit slowly precessed from an Equator-crossing time (ascending node) of 1400 hours to 2000 hours. The combination of orbit geometry and sensor design resulted in direct solar radiation and associated loss of transmission much greater on one side than the other as the spacecraft went into and from sunlight. This asymmetric degradation affects the interpretation of the calibration, the measurements of solar radiation reflected by the Earth and the retrieval of



a. ground track for NOAA 9 in March 1985



b. ground track for NOAA 9 in March 1988



c. ground tracks for NOAA 9 in March 1991

Figure 1: Progression of ground tracks as NOAA9 orbit precessed.

albedo distribution over the Earth. The retrieval of Earth-emitted radiation is also affected, as it is computed by subtracting the reflected solar radiation from the total radiation measurement. As a consequence, there was little interest in processing the WFOV data. However, fig. 1a and 1b show that the NOAA 9 orbit provides excellent viewing of the Earth during daylight at high northern latitudes and during night over high southern latitudes over the data period from 1985 through 1992. The NOAA 10 orbit likewise precessed and provided complimentary measurements of daylight measurements at high southern latitudes and nighttime measurements at high northern latitudes. The ERBS WFOV measurements have provided an excellent data set between 57°S and 57°N. As a system, the three spacecraft have provided good coverage over the Earth for the period 1985 through 1992. A technique is needed to take into account the non-uniform degradation pattern of the quartz dome in order to produce an accurate radiation budget data set from the NOAA 9 WFOV measurements.

This paper presents a method for computing the degradation pattern of the quartz dome over the time period of interest. The degradation is due to solar radiation, which darkens the dome. Given the spacecraft orbit, the pattern of dosage of solar irradiance on the dome is computed over the time period. It is assumed that the transmission loss of the dome at a point is a function of solar irradiance dosage. This function is computed from an integral equation which relates the dosage pattern over the dome to the solar calibrations. Once this transmission function is calculated, the dosage pattern is used to compute the transmission pattern over the dome. . The transmission pattern is incorporated in calculation of the shape factors for processing the shortwave measurements.

This paper begins with a description of the radiometer and the calibration results over the period February 1985 through December 1992. The degradation problem is then formulated and the required instrument-Sun geometry is described, from which the dosage of solar insolation is computed.

2. INSTRUMENT

Figure 2 shows a cross section of the shortwave channel of the WFOV radiometer. It consists of an active cavity radiometer (ACR) covered by a quartz dome, which transmits reflected solar radiation (shorter than 5 μm) and filters out radiation Earth-emitted radiation (longer than 5 μm). A secondary aperture limits the field of

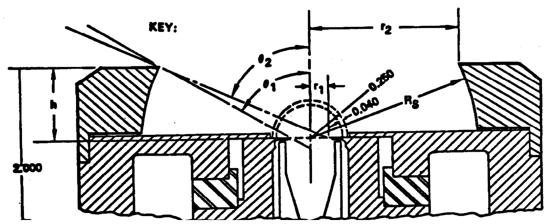


Figure 2: Cross section of WFOV radiometer

view so that radiation from the entire Earth's disc, from limb to limb, enters the ACR. There is a 2° gap around the Earth's disc to allow for spacecraft altitude variation and extent of the atmosphere. As the spacecraft going around its orbit enters or leaves sunlight, the Sun appears within this gap so that direct sunlight impinges on the dome and causes degradation

The WFOV radiometers are mounted on a beam. In order to calibrate them, the beam rotates so that the Total radiometer views an internal blackbody, then to a position so that the radiometers view the Sun through a calibration port as fig. 3 shows. The nonscanner instrument includes a Solar Monitor so the Sun's flux is a known amount. These calibrations were performed at frequent intervals (Lee et al., 19??) and fig. 4 shows the results.

3. FORMULATION OF DEGRADATION

The dome degradation is defined to be the loss of transmission of the dome. In order to evaluate the dome degradation, we assume that the degradation at a point on the dome is a function of the total direct solar dosage, i.e. the integrated amount of sunlight over time which impinges on the dome. The instantaneous sunlight on the dome at a point $\boldsymbol{r}$ is

$$f(\boldsymbol{r}) = S\, g(\gamma)\, \boldsymbol{h}.\boldsymbol{n}$$

where S is the solar irradiance, $\boldsymbol{h}$ is the unit vector

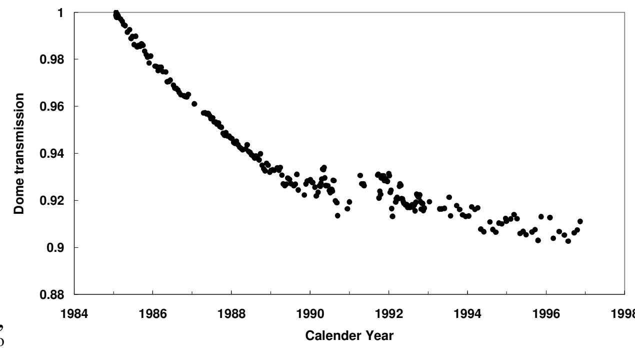
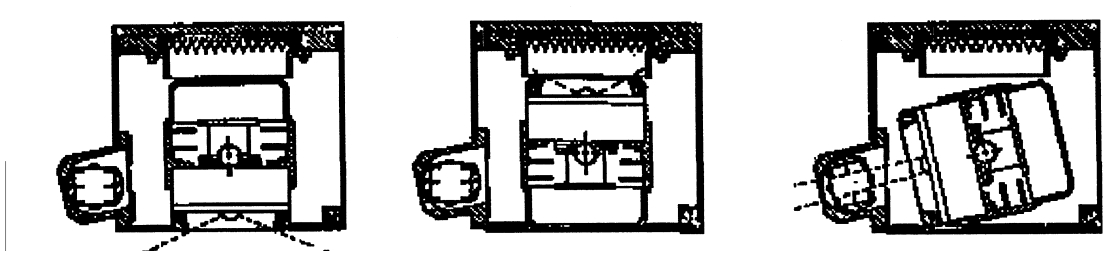


Fig. 3: Dome transmission of shortwave WFOV channel for NOAA 9 ERBE from February 1985 through December 1996.

toward the Sun and $\boldsymbol{n}$ is the unit vector normal to the dome at $\boldsymbol{r}$. and $g(\gamma)$ accounts for occultation of the Sun by the secondary aperture or the Earth-atmosphere system, with γ being the angle from the centre of the Sun t the edge of the occulting object. In order to compute $g(\gamma)$, it is assumed that the Sun is uniformly bright across its disc and that the Earth-atmosphere system can be considered to have a hard edge, i.e. partial transmission or refraction of sunlight by the atmosphere is neglected. Thus $g(\gamma)$ is simply the fraction of the Sun's disc in view of the point $\boldsymbol{r}$. $f(\boldsymbol{r})$ is integrated in time to give the dosage pattern over time.

The degradation is assumed to occur at the surface of the dome, i.e., the thickness of the dome is negligible in comparison to the thickness. Considering the unknowns of the mechanism of degradation, this approximation is inconsequential.

In order to compute the flux across the dome and the dosage, we define an instrument coordinate centered with the dome and locate the Sun in this coordinate system as a function of time. The computation is simply an exercise in geometry.



a. Earth viewing b. viewing internal black body c. Viewing Sun through port

Figure 3: Nonscanner locations for a. Earth viewing, b. rotated for Total channel to view internal blackbody for calibration and c. rotated for Shortwave and Total channels to view Sun through calibration ports

Instrument Coordinate System: A Cartesian coordinate system is defined with its origin at the center of the dome, the z-axis vertical, towards the Earth's center, and the x-axis parallel to the spacecraft velocity vector. A spherical polar coordinate system is next defined for the dome, using the z-axis as the polar axis. The dome is partitioned into a set of quasi-equal area tiles, and the centre of each tile is taken as a point for computing the flux and dosage. The tiles are each 5^o in latitude, with longitudinal extent to maintain approximately equal area. As a result there are 1058 grid points approximately equally spaced to describe the flux and dosage distribution over the dome. For each grid point j the $\boldsymbol{r}_j$ and $\boldsymbol{n}_j$ are computed.

Location of Sun: Figure 5 shows the geometry of the Sun relative to the spacecraft and its orbit. The normal to the orbit plane is defined by the convention of the right-hand rule applied to the spacecraft velocity. The normal to the orbit plane is parallel to the y- axis of the instrument coordinate system. The angle between the normal to the orbit and the Earth-Sun line is denoted as β. The orbit normal and the Earth-Sun line determine a plane; the intersection of this plane with the orbit plane determine a line. The angle from this line to the

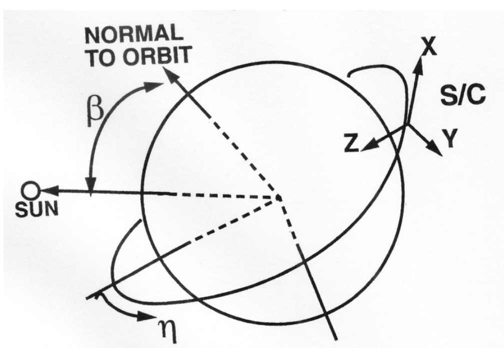


Figure 5: Orbit-Sun geometry

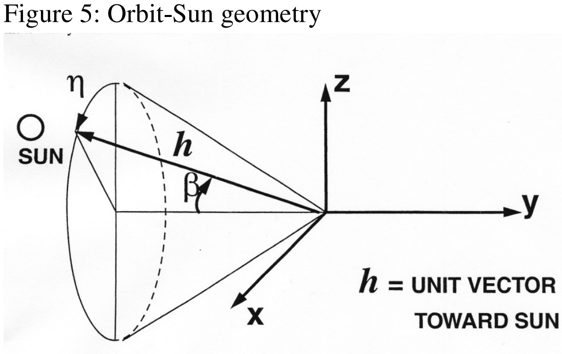


Figure 6: Location of Sun in instrument coordinates.

spacecraft is denoted as η. The angles β and η determine the location of the Sun relative to the spacecraft so that the components of h are computed in terms of β and η. Figure 6 shows the location of the Sun in the instrument coordinate system in terms of these angles

The beta angle is determined by the orbital inclination, the Equator-crossing time and the solar declination. Figure 7 shows the Equator-crossing time over the period February 1985 through Decemer 1992

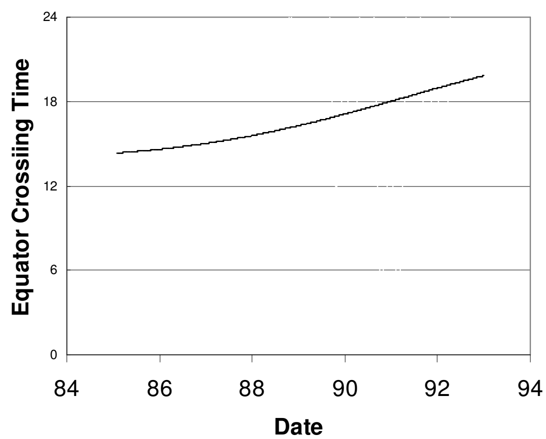


Figure 7: Equator-crossing time over the period February 1985 through Decemer 1992.

Given β, the range of η for which the dome is exposed to sunlight can be computed. For η values within the range of illumination the $\boldsymbol{h}$ and the pattern of flux normal to the surface of the dome can be calculated, so that the dosage for thje orbit is known. This posage pattern is summed from day to day as β varies to produce a time history of dosage. Figure 8 shows the dosage pattern after exposure from February 1985 through December 1988 and fig. 9 shows the doasge pattern for February 1985 through December 1992. In each case the pattern has been normalized with the point of greatest doasge taken as unity.

The Sun is at the left of the figure, at azimuth = 270^o. Because of the symmetry of figures 5 and 6, the insolation pattern during sunrise will be repeated at sunset, but its position will be reflected across the y-axis. As a consequence, the dosage for any orbit will be symmetric about the y-axis.

Figures 8 and 9 show that the insolatiopn dosage is large on one side due to the orbit-spacecraft-Sun geometry. Further, the degradation will be greatest on the side of the dome from which the largrest part of the reflected solar radiation is

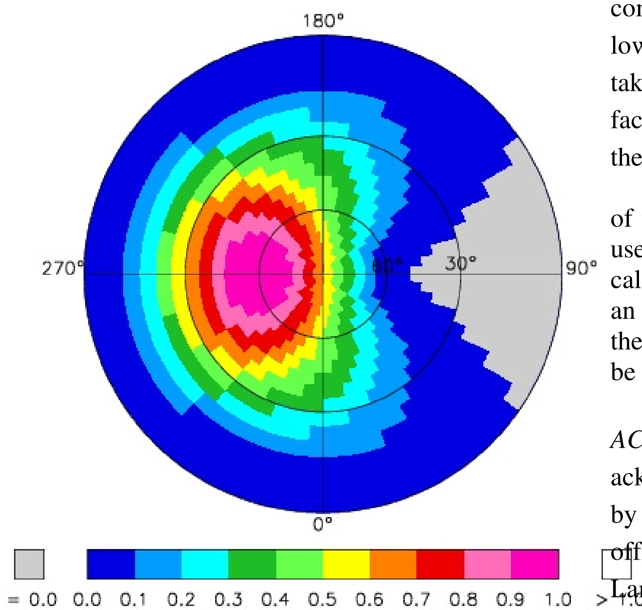


Fig. 8: Solar dosage pattern over dome for period February 1985 through December 1988.

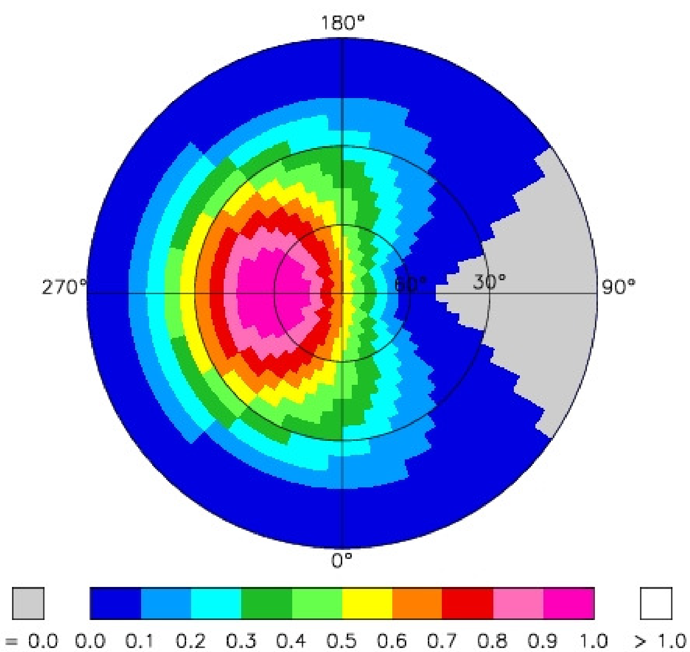


Fig. 9: Solar dosage pattern over dome for period February 1985 through December 1992.

coming. Consequeently, the measurement will be lower than it should be. The degradation must be taken into account in the computation of the shapee factor which is used to calculate the albedo from the measurement.

The next step is to compute the transmission of the quartz as a function of insolation dosage by use of the history of dosage pattern and the calibaration curve of figure 4. These are related by an integral equation. Given the transmission curve, the transmission pattern and the shape factors can be computed as a function of tim ein orbit.

ACKNOWLEDGEMENTS: The authors gratefully acknowledge the support of the CERES Program by the Earth Science Office of the Washington office of NASA and the Sciences Directorate of the Langley Research Centre