The Status of the NOAA Outgoing Longwave Radiation Data Set

Arnold Gruber1 and Arthur F. Krueger2

Abstract

National Oceanic and Atmospheric Administration (NOAA) satellites have provided over eight years of observations from which estimates of the earth's total longwave emittance can be derived. Changes in satellite instrumentation, orbit, and algorithms used in obtaining these estimates are briefly summarized. The algorithms used by NOAA in obtaining a longwave radiation data set are provided.

1. Introduction

More than eight years of twice daily outgoing longwave radiation estimates are now available from NOAA satellites. These estimates, which cover the entire earth, have been obtained from several polar-orbiting satellites. They are part of a record that was originally developed for monitoring the earth-atmosphere radiation balance (Winston et al., 1979; Gruber and Winston, 1978). These data have been used in a variety of diagnostics and climate sensitivity studies (e.g., Ohring and Gruber, 1983, Lau and Chan, 1983 a,b; and Weickmann, 1983) and have been particularly useful for routine monitoring of cloudiness and rainfall over the tropics. For example, the most recent El Niño–Southern Oscillation (ENSO) event over the tropical Pacific has been revealed in great detail (Climate Analysis Center, 1982–83).

Since the beginning of the NOAA outgoing longwave radiation data set in June 1974, there have been several changes in satellites, their orbits, and instrumentation, as well as in the procedures for treating the observations. A detailed discussion of the data reduction procedures, radiometer characteristics, and orbital parameters of the satellite systems is presented by Gruber (1977), and Gruber et al. (1983). Highlights of some of these changes and their impact on the quality of the eight-year record are presented here. In addition, changes that will be made to this data set and plans for developing an eight-year longwave climatology are discussed.

The changes that have affected this record are essentially of two kinds. The first is the change in equator crossing times that has occurred since June 1974. The second involves several changes in both instrumentation and in the algorithm used for deriving the total longwave emittance from window channel measurements.

2. Changes in equator crossing times

There have been four changes in equator crossing times since the eight-year record began (Table 1). The longest continuous portion of the record, 45 months, is that from the NOAA scanning radiometer (SR) series3 which extends from June 1974 to February 1978 and had equator crossings at 9:00 a.m. and p.m.4 This portion of the record was published in an atlas by Winston et al. (1979) and has been used as a preliminary base period for the outgoing longwave radiation measurements that have since been acquired. After a ten-month gap in 1978, the record resumed in January 1979 with TIROS N; however, it continued for only 13 months, making it the shortest subset of the entire record. Equator crossings for this satellite were at about 3:30 a.m. and p.m. TIROS N was replaced in February 1980 by NOAA 6, which had equator crossings at 7:30 a.m. and p.m. The most recent satellite

Table 1. Longwave radiation observations from NOAA spacecraft.

<table>
<thead>
<tr>
<th>Satellite</th>
<th>Equator Crossing</th>
<th>Period of Record</th>
<th>Number of Months</th>
</tr>
</thead>
<tbody>
<tr>
<td>NOAA SR Series</td>
<td>9:00 a.m.–9:00 p.m.</td>
<td>June 1974–Feb. 1978</td>
<td>45</td>
</tr>
<tr>
<td>Tiros N</td>
<td>3:30 a.m.–3:30 p.m.</td>
<td>Feb. 1980–July 1981</td>
<td>17</td>
</tr>
<tr>
<td>NOAA 6</td>
<td>7:30 a.m.–7:30 p.m.</td>
<td>Sept. 1981–present</td>
<td>21</td>
</tr>
<tr>
<td>NOAA 7</td>
<td>2:30 a.m.–2:30 p.m.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3This record actually consists of measurements from four satellites, namely NOAA 2,3,4, and 5.
4All times are local sun time.

© 1984 American Meteorological Society

Vol. 65, No. 9, September 1984
FIG. 1. Time series of the day-minus-night difference for the global monthly average outgoing longwave radiation (emittance). Note the discontinuity that occurs with a change in satellite.

The record, which began in August 1981 with NOAA 7, forms the second-longest segment of the eight-year record and has equator crossings at 2:30 a.m. and p.m. Current plans call for the continued processing of NOAA satellite radiation data.

Even if there were no gaps in the eight-year record, changes in equator crossing times permit only a temporally inhomogeneous radiation record; a sample of daytime observations for the entire record would consist only of measurements taken at four different times: 7:30 a.m., 9:00 a.m., 2:30 p.m., and 3:30 p.m. The possible effect of sampling at various times of the day is apparent in the day-minus-night differences shown in Fig. 1. Typically for afternoon and nighttime observations this difference is of the order of 5-6 W·m⁻²—note the TIROS N and NOAA 7 portions of the record. In contrast, the NOAA 6 observations, which were near sunrise and sunset, show the smallest differences and these are of the order of 1-2 W·m⁻². Since these differences are area-weighted global averages, they suggest a diurnal cycle exists for the earth as a whole. This can be examined by compositing the global average longwave emittance observations as a function of the time of day for each of the four satellites, as shown in Fig. 2. While the observations are not spaced so as to adequately define the shape and magnitude of the diurnal variation, an amplitude of 6-7 W·m⁻² is suggested with an afternoon maximum and a morning minimum. Much of this diurnal variation is probably contributed by the Northern Hemisphere. Day-minus-night differences over North Africa and South Central Asia, for example, are the largest for the earth and average as high as 50-60 W·m⁻² (TIROS N). In contrast, over the Southern Hemisphere these differences are small except for portions of South America and Australia.

Figure 2 is not presented in order to define the diurnal variation in outgoing longwave radiation. This could be done more accurately from the various geostationary satellites as was attempted for METEOSAT by Saunders and Hunt (1980), and Saunders et al. (1983). It does suggest, however, that the diurnal longwave radiation cycle is apparent even in the global average and therefore should be considered in future satellite launches. In the past this was not a primary consideration, since these measurements were not planned to be part of a climate record. Archiving these data in a convenient format represented a significant breakthrough (Gruber and Winston, 1978). Since then, the utility of this data set for research and climate monitoring has been clearly established and consequently standardized observation times warrant a high priority.

FIG. 2. Twice-daily observations of the global annual average outgoing longwave radiation for each satellite plotted against time of equator crossing.
FIG. 3. Zonal annual average outgoing longwave emittance as a function of latitude for: NOAA SR series, TIROS N, NOAA 6, and NOAA 7. Global averages are 232, 229, and 230 W m⁻², respectively.

It is difficult to assess the effect of these changes in equator crossings on the eight-year record. To minimize this effect day and night observations were averaged. Fig. 3 suggests that this is a reasonable approach. Zonal profiles for the NOAA SR, TIROS N, NOAA 6 and NOAA 7 are shown in this figure. The differences between these four sets of observations are generally small and are probably indicative of real interannual variability in addition to the changes in satellites and their equator crossings.

3. Changes in computational procedures and radiometers

In addition to the changes in satellites and, in particular, the satellite equator crossing times, there have been several changes in the algorithm used to convert from the window channel radiometer measurements to the total outgoing longwave emittance.

The window channel radiometer itself has been changed several times over the past eight years (Fig. 4). Initially, the window channel for the SR series extended from 10.5 to 12.5 μm, but with TIROS N and NOAA 6 the channel was shifted and narrowed (10.5–11.5 μm). NOAA 7 employed two infrared channels, but only the upper channel, which extends from 11.5 to 12.5 μm, has been used for this series.

The initial derivation of the total outgoing longwave emittance from window radiance measurements was made by Wark et al. (1962). This relation, derived using 99 different atmospheres covering a broad range of temperatures, humidities, and cloudiness, was determined to be linear. Additional studies by Abel and Gruber (1979) indicated that a nonlinear regression relation gave a superior fit. This relation was used to correct the entire record then available (Gruber and Winston, 1978). The introduction of TIROS N and NOAA 6, which had different window channel radiometers, required a new algorithm; it too was based on the calculations of Abel and Gruber. Later, when NOAA 7 was launched, an algorithm based on the updated calculations of Ellingson and Ferraro (1983) was used.

Recently, Ohring et al. (1984) reviewed the procedure for converting window radiance to total outgoing longwave emittance and derived a new relation. They derived this relation from data obtained from the NIMBUS 7 satellite which measured both the total longwave emittance using data from the Earth Radiation Budget (ERB) sensors and the radiance in the 10–12 μm infrared window measured by the Thermal Infrared Radiometer (THIR). This study provided convincing evidence that the theoretical algorithms previously used have a positive bias of 13 W m⁻² with respect to the ERB measurements. It turns out that this bias is approximately the radiative imbalance that is indicated when the annual global mean absorbed solar radiation is compared with the longwave emittance (Ohring and Gruber, 1982). The relation...
previously-calculated flux values are described in the Appendix. Currently, these corrections are being applied to the entire record. When this is completed, it will replace the existing record that has been archived at NESDIS. This record will also form the basis for a "climatology" that will be produced and published as an atlas. This, in turn, will be used as the climatological base period for all future anomaly computations.

Only the outgoing longwave radiation was considered in this study. It is anticipated, however, that a similar analysis for the solar radiation and albedo will be conducted.

**FIG. 5. Total outgoing longwave radiation and flux equivalent blackbody temperature as a function of equivalent blackbody window temperature for the algorithm of Ohring et al., 1984.**

they derived is the following, shown in Fig. 5.

\[
T_F = (a + b \cdot T_{\text{THIR}}) T_{\text{THIR}}
\]

Here \(a = 1.2149\), \(b = 0.001055\{K\}^{-1}\), \(T_{\text{THIR}}\) is the Nimbus 7 THIR equivalent blackbody window temperature, and \(T_F\) is the flux equivalent blackbody temperature. This is translated to the outgoing longwave emittance with the Stefan-Boltzmann law, \(F = \sigma T_F^4\). Tests of Eq. 1 against independent data indicate little or no bias and a root mean square (RMS) difference of approximately 11 W-m\(^{-2}\) for an individual estimate. Time and space averages would reduce these errors significantly. A more complete discussion is provided by Ohring et al. (1984). Introduction of this new algorithm resulted in a drop of about 11 W-m\(^{-2}\) in the global average.

**4. Current plans**

It is important that this record of the outgoing longwave radiation be as homogeneous as possible. Consequently, the Climate Analysis Center (CAC) and National Environmental Satellite, Data, and Information Service (NESDIS) have begun to apply corrections based on the algorithm of Ohring et al. to the entire record. The direct application of this algorithm to the past record is not possible, since only flux values rather than window temperatures are available. The THIR window and IR windows on the four satellites that make up this record are all different in their spectral responses and, consequently, the equivalent blackbody window temperatures are all different (see Fig. 4). Thus, it is necessary to relate the THIR window radiance to the window radiances of each satellite, e.g., NOAA-SR(F21), TIROS N, NOAA 6, and NOAA 7. The relations that will allow corrections of the previously-calculated flux values are described in the Appendix. Currently, these corrections are being applied to the entire record. When this is completed, it will replace the existing record that has been archived at NESDIS. This record will also form the basis for a “climatology” that will be produced and published as an atlas. This, in turn, will be used as the climatological base period for all future anomaly computations.

Only the outgoing longwave radiation was considered in this study. It is anticipated, however, that a similar analysis for the solar radiation and albedo will be conducted.

### Appendix. Algorithms

Relationships between the THIR windows and NOAA windows were derived from radiance calculations performed by Ellingson and Ferraro (1983) for a set of 100 different atmospheres with varying cloud conditions. The following set of equations were derived through a regression analysis covering a range of window temperatures from about 190 to 320 K:

For NOAA SR data,

\[
T_{\text{THIR}} = -0.863 [K] + 1.0035 T_{\text{SR}};
\]

for TIROS N and NOAA 6 data,

\[
T_{\text{THIR}} = 3.38 [K] + 0.9856 T_N; \text{ and}
\]

for NOAA 7 data,

\[
T_{\text{THIR}} = -3.66 [K] + 1.015 T_7,
\]

where \(T_{\text{THIR}}, T_{\text{SR}}, T_N,\) and \(T_7\), represent equivalent blackbody window temperatures from the respective satellites. The regression between the various channels and THIR essentially explained 100% of the variance over the 190 to 320 K temperature range. The standard errors of estimate are 0.04, 0.1, and 0.1 K for Eq. (2)-(4), respectively.

Using the relationships (2)-(4) with (1), calculations of the flux for each radiometer, designated \(F_N\) were performed and regressed against the original archived flux computations, designated \(F_0\). The resulting equations,

for NOAA SR data,

\[
F_N = 0.7920 F_0 + 6.357 \times 10^{-4} [m^2 \cdot W^{-1}] F_0;
\]

for TIROS N and NOAA 6 data,

\[
F_N = 0.8115 F_0 + 5.542 \times 10^{-4} [m^2 \cdot W^{-1}] F_0;
\]

and for NOAA 7 data,

\[
F_N = 0.8532 F_0 + 3.887 \times 10^{-4} [m^2 \cdot W^{-1}] F_0,
\]

represent corrections to the currently-archived data. The regressions between the new and old fluxes were excellent; nearly 100% of the variance was explained. Standard errors of estimates were about 0.5 W-m\(^{-2}\) in all cases.

After 1 August 1983, the flux values obtained from NOAA 7 will be calculated with the improved equation, which is obtained directly from (1) and (3) and is

\[
T_F = -4.454 [K] + 1.2409 T_7 - 0.001087 [K^{-1}] T_7^2.
\]
References


announcements

Graduate research assistantship in atmospheric science

The Atmospheric Science Graduate Group of the University of California at Davis has a graduate research assistantship available in the area of climate dynamics. This position involves using a general circulation model to study oceanic-influences upon the nonlinear life-cycles of midlatitude wavelike cyclones. A salary of up to $10,600 per year will be awarded for the qualified M.S. or Ph.D. level student. Previous experience with meteorology is beneficial but not essential. For more information, write to: Prof. Richard Grotjahn, Graduate Advisor, Department of Land, Air and Water Resources, University of California, Davis, CA 95616.

Videotapes documenting NOAA research projects available

The Environmental Research Laboratories of the National Oceanic and Atmospheric Administration are making available to AMS chapters videotapes documenting several research projects, on a loan basis.

Four tapes are presently available: 1) a nine-minute documentation of NOAA's National Weather Service airborne snow survey to determine moisture content of snow fields in the upper mid-West, 2) a 10-minute documentation of severe thunderstorms research at the National Severe Storms Laboratory, Norman, Okla., focusing upon use of Doppler radar and lightning research, 3) a 20-minute documentation of the 1984 Arctic Cyclone research conducted by the Environmental Research Laboratories from Iceland and Norway, and, 4) an 8-minute documentation of the activities of the Space Environment Services Center, which has responsibility for monitoring the sun and issuing forecasts and notifications of solar disturbances, including solar flaring.

The documentaries are available in 3/4-inch videotape cassettes and 1/2–h VHS cassettes. For more information, contact Public Affairs, NOAA/ERL, 325 Broadway, Boulder, CO 80303, phone (303)497-6286.

Coastal Ocean-Atmosphere Shoreline Transport Study (COASTS) establishes organizing committee

An organizing committee has been established to develop an observational and modeling study of coastal mesoscale atmospheric circulations during the next several years. The committee includes: Bob Bornstein, Project Coordinator; Walt Lyons, Observations [air quality] Coordinator; Sethu Raman, Observations [meteorological] Coordinator; Roger Pielke, Modeling Coordinator; and Gil Raynor, Database Coordinator. Please contact Dr. Robert Bornstein, San Jose State University, San Jose, CA 95114, phone (408)277-2311, if you are interested in participating in the planning of COASTS.

(continued on page 992)