1. INTRODUCTION

The International Satellite Cloud Climatology Project (ISCCP), the first project of the World Climate Research Program (WCRP), was established in 1982 (Schiffer and Rossow 1983) to collect reduced resolution, narrowband (0.6 and 11 μm wavelengths) radiance measurements (Stage B3 data) made by the imaging radiometers on the operational weather satellites (Schiffer and Rossow 1985; Rossow *et al*. 1987). The primary focus of the first phase (1983 - 1995) was on the elucidation of the role of clouds in the radiation balance (top of the atmosphere and surface) that determines the climate. In the second phase (1995 onwards), the analysis also concerns improving understanding of the global hydrological cycle in which clouds play a key role. For both purposes, variations of the **physical** properties of clouds need to be measured with sufficient accuracy to resolve cloud effects over the whole range of scales covered by weather and natural climate variability. The cloud properties are inferred from the satellite-measured radiances which, therefore, must be accurately calibrated.

To obtain global coverage, observations are combined from up to five geostationary satellites (METEOSAT, GMS, GOES-EAST, GOES-WEST and INSAT) and up to two polar orbiting NOAA satellites (only one year of INSAT data have been obtained). The radiometric calibrations of all infrared and visible B3 radiances have been normalized to a common reference standard and the absolute calibration of that standard determined (other wavelengths are collected in the B3 dataset but not re-calibrated). For the first set of cloud products, covering the period from July 1983 through June 1991 (Rossow and Schiffer 1991), the reference standard was the AVHRR on NOAA-7 (Brest and Rossow 1992, Desormeaux et al. 1993, Rossow et al. 1992). The estimated overall uncertainty in the radiance calibrations was ± 5-10% for the visible and ± 2-3% for infrared (± 1.5-2.5K at 300K in brightness temperature).

Several retrospective examinations of the 8-year ISCCP cloud data record have revealed some specific artifacts in the calibration record of the first ISCCP datasets that, although just within the estimated uncertainties, are systematic enough to reduce the quality of the long-term cloud datasets. These quantitatively small problems with the calibration would not have been recognized without examining the whole long-term data record, suggesting that the production of high-quality datasets for climate studies requires an iterative analysis. The decision was made to refine the ISCCP calibration and analysis scheme and to re-process all of the older data, as well as newer data, to produce a homogeneous data record. This document describes the refinements of the calibration procedures implemented to reduce these artifacts, describes a new calibration dataset (Stage BT) now being archived, and provides new calibration tables to replace those given in the previous report on calibration (Rossow et al. 1992).

All of the ISCCP datasets are produced by the

ISCCP Global Processing Center
NASA Goddard Space Flight Center
Institute for Space Studies
2880 Broadway
New York, NY 10025
USA

and are available from

ISCCP Central Archive
Satellite Data Services Division
NOAA/NESDIS
World Weather Building, Room 100
Washington, DC 20233
USA

2. <u>CALIBRATION PROCEDURES</u>

2.1. Overview

The ISCCP calibration procedure concerns only the infrared (wavelength ≈ 11 μm) and visible (wavelength ≈ 0.6 μm) radiances common to all polar orbiting and geostationary satellites. Although radiances at other wavelengths are collected, when available, they are not re-calibrated. The procedure has five parts (Rossow et al. 1992):

(1) normalization of each geostationary satellite radiometer to the standard "afternoon" polar orbiter every third month (more frequently as needed) by comparing coincident and co-located radiance measurements,

(2) elimination of shorter-term calibration variations for the geostationary radiometers by interpolation of the 3-monthly normalizations and examination of the complete time record of individual images at three hour intervals over each month,

(3) monitoring of the reference polar orbiter radiometer calibration to determine corrections that remove sudden changes and slow instrument drift,

(4) normalization of subsequent "afternoon" polar orbiter radiometer calibrations, when they replace the original reference standard, and of "morning" polar orbiter radiometers to the "afternoon" reference, and

(5) determination of an absolute radiometric calibration for the reference satellite radiometer by comparison to aircraft, surface and other vicarious estimates.

The first step is performed at the ISCCP Satellite Calibration Center in Lannion, France, and the other steps are performed by the ISCCP Global Processing Center in New York, USA (Desormeaux et al. 1993, Brest and Rossow 1992). The new procedure includes an additional check on the first step and refinement of the third and fourth steps (see a forthcoming article, Brest et al. 1996).

2.2. Evidence for Problems

2.2.1. Geostationary Radiometer Calibration

The procedure to normalize the geostationary satellite radiometers to the polar orbiter is generally performed every third month, although it is occasionally performed monthly when there is a suggestion of calibration changes in between the standard months (Desormeaux et al. 1993). However, the linear interpolation of calibrations over the two intervening months did not capture all the changes in radiometer performance as shown by statistics collected during the first processing of the ISCCP datasets. A process was designed to detect unusually large calibration differences and to apply corrections to the monthly mean cloud products (Stage C2 data). The procedure (described more fully below) collects, for each geostationary satellite, frequency histograms of differences of the retrieved cloud top and surface temperatures and cloud and surface visible reflectances from all measurements that are coincident and co-located with the afternoon polar orbiter ("overlapping" observations). The time record of the modal differences shows that rms deviations of temperatures are ≈ 0.9K and deviations of visible reflectances are ≈ 0.03, but also indicates that the normalizations for some months deviate by larger amounts and are not as accurate as for the overall dataset (Figure 1).

That the results in Figure 1 actually represent systematic normalization errors is illustrated in Figure 2 by one example of an artifact in the geographic distributions of the physical quantities at the boundary between two geostationary satellites. Figure 2 (upper panel) shows a conspicuous boundary in the sea surface temperatures in the central Pacific, corresponding to an unusually large modal difference in temperatures for the GOES-WEST satellite on 5 September 1987 (Figure 1). Direct sensitivity tests were performed, where the calibration was artificially changed by a known amount and the data processed as before, to show that the procedure is very sensitive to calibration differences between satellites. Since most of the larger differences shown in Figure 1 are for months not directly normalized by the SCC in the original processing, this problem arises because the geostationary satellite radiometers occasionally change calibration more rapidly than on a three month time scale and the routine procedures did not detect all of these changes. Some differences in Figure 1 for GOES in 1987 are produced by incomplete sampling because of an unusually large number of missing images.

2.2.2. Polar Orbiter Radiometer Calibration

A number of authors have proposed other vicarious methods to monitor changes in the AVHRR calibration (Staylor 1990, Che and Price 1992, Teillet et al. 1993, Kaufman and Holben 1993, Teillet and Holben 1994, Rao et al. 1994, Frouin and Simpson 1995); however, these methods all differ from the ISCCP method in using very small, geographic targets as their reference, whereas the ISCCP method uses the whole Earth surface as a statistical population of targets (Brest and Rossow 1992). There are enough aircraft measurements, processed by the same procedure, to examine instrument drift for only two AVHRRs: on NOAA-9 and NOAA-11. Figure 3 compares a collection of these results: the instrument drift rates implied by the different analyses differ from the old ISCCP values by as much as 30%, although the new ISCCP drift rates are in much better agreement with the aircraft results. Nevertheless, these results suggested that the radiometer drift rates are uncertain by significant amounts, so that our procedure for monitoring instrument drift rates needed to be re-examined.

At the time the ISCCP procedures were completed, there was only one available case that provided validation of the normalization of two AVHRRs. These results, shown as the last aircraft point in the NOAA-9 plot and the first aircraft point in the NOAA-11 plot in Figure 3 (open squares) confirmed to within a few percent the normalization obtained from the ISCCP analysis of three weeks of overlapping observations from these two radiometers (Brest and Rossow 1992). However, examining the whole NOAA-9 and NOAA-11 record shown in Figure 3 suggests that this normalization was actually biased because these two aircraft points do not lie on the general trend for either satellite. This result emphasizes that the uncertainties of the aircraft calibrations are nearer $\pm$ 10% and suggests that the scatter of the aircraft values about the trend lines shown in Figure 3 is a result of this uncertainty, rather than indicative of real shorter-term calibration changes.

Examinations of anomalies in global mean values of the retrieved cloud and surface parameters over the original 8-year data record (1983-1991) show two artifacts that coincide with the changes of the NOAA polar orbiter satellite used as the calibration reference standard (Klein and Hartmann 1993). Figure 4 also illustrates this effect by showing the apparent trends in the average cloud properties caused by systematic changes in both the measured cloud top temperatures retrieved from the IR radiances and the optical thicknesses from the VIS radiances. The transitions occurred at the change-over from NOAA-7 to NOAA-9 between January and February 1985 and from NOAA-9 to NOAA-11 between October and November 1988 (see Figures 6 and 9). The original methodology (Brest and Rossow 1992) for Channel 1 used NOAA-7 as the standard and used several weeks of overlapping data at the transitions to normalize new satellites to the previous satellite and thus to the NOAA-7 standard, creating a relative calibration spanning the entire data record. Figure 6 shows that the offsets in the old ISCCP VIS calibrations are residuals of the much larger differences in the original calibrations for these instruments. Likewise, adjustments to the relative IR calibrations became necessary when the operational calibration procedure was changed by NOAA in October 1987; the offsets in Figure 9 are again residuals of larger offsets in the original calibration.

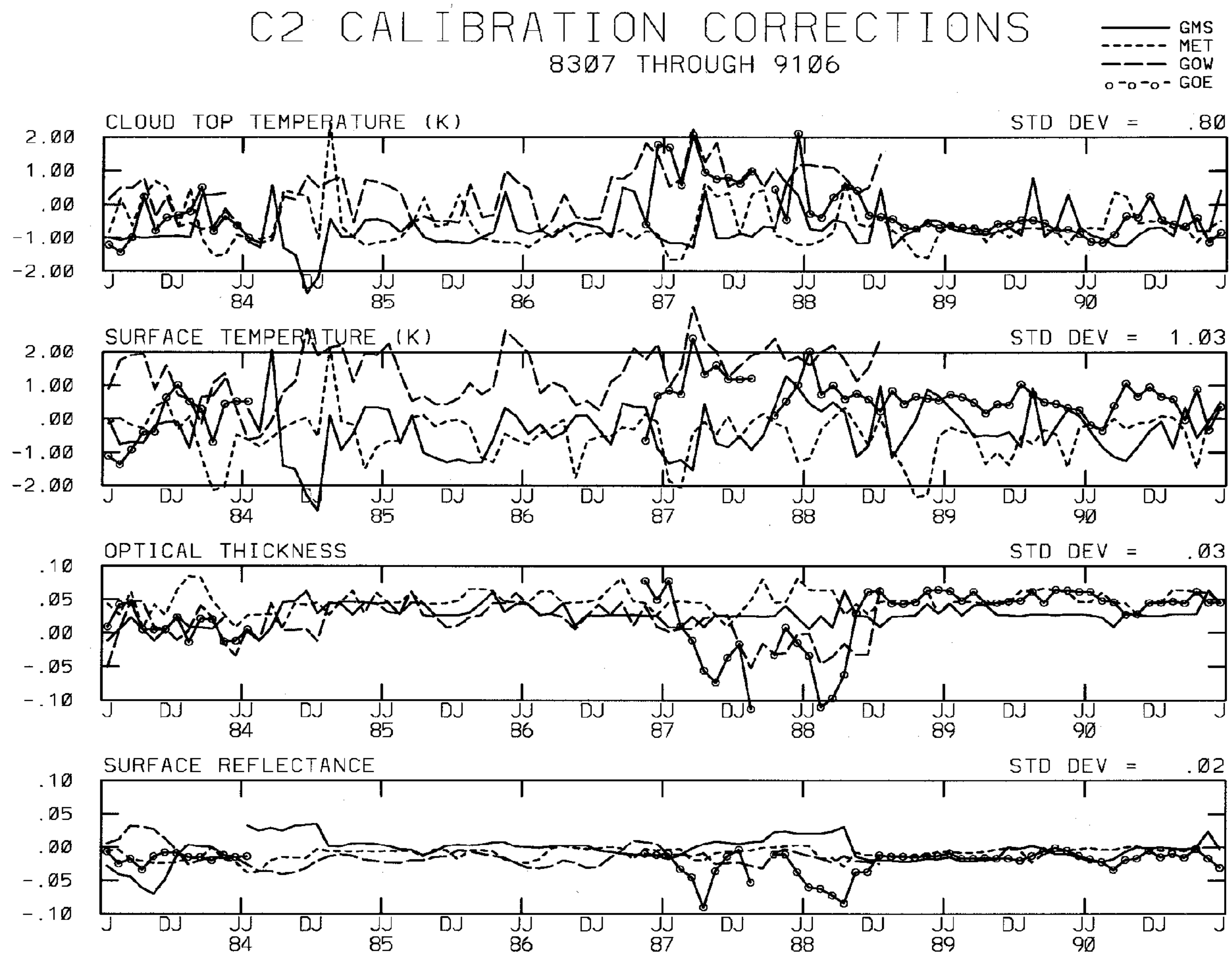

Figure 1. History (July 1983 – June 1991) of modal differences between retrieved cloud top temperature, surface temperature, cloud optical thickness (in reflectance units), and surface visible reflectances from overlapping geostationary and polar orbiting satellite observations. Disttributions for each month are differences of individual observations at 3hr and 280 km resolution. The polar orbiter is the afternoon NOAA satellite. The geostationary satellites are the METEOSAT series (short-dashed line), the GMS series (solid line) , the GOES-EAST series (long-dashed line), and the GOES-WEST series (line with circles).

Figure 2. Global map of retrieved surface temperatures for 5 September 1987 showing in the upper panel a large difference between the domain covered by GMS and GOES-WEST in the first ISCCP datasets and in the lower panel the same data after correcting the infrared calibration of both GOES-WEST and GOES-EAST based on the monthly modal differences.

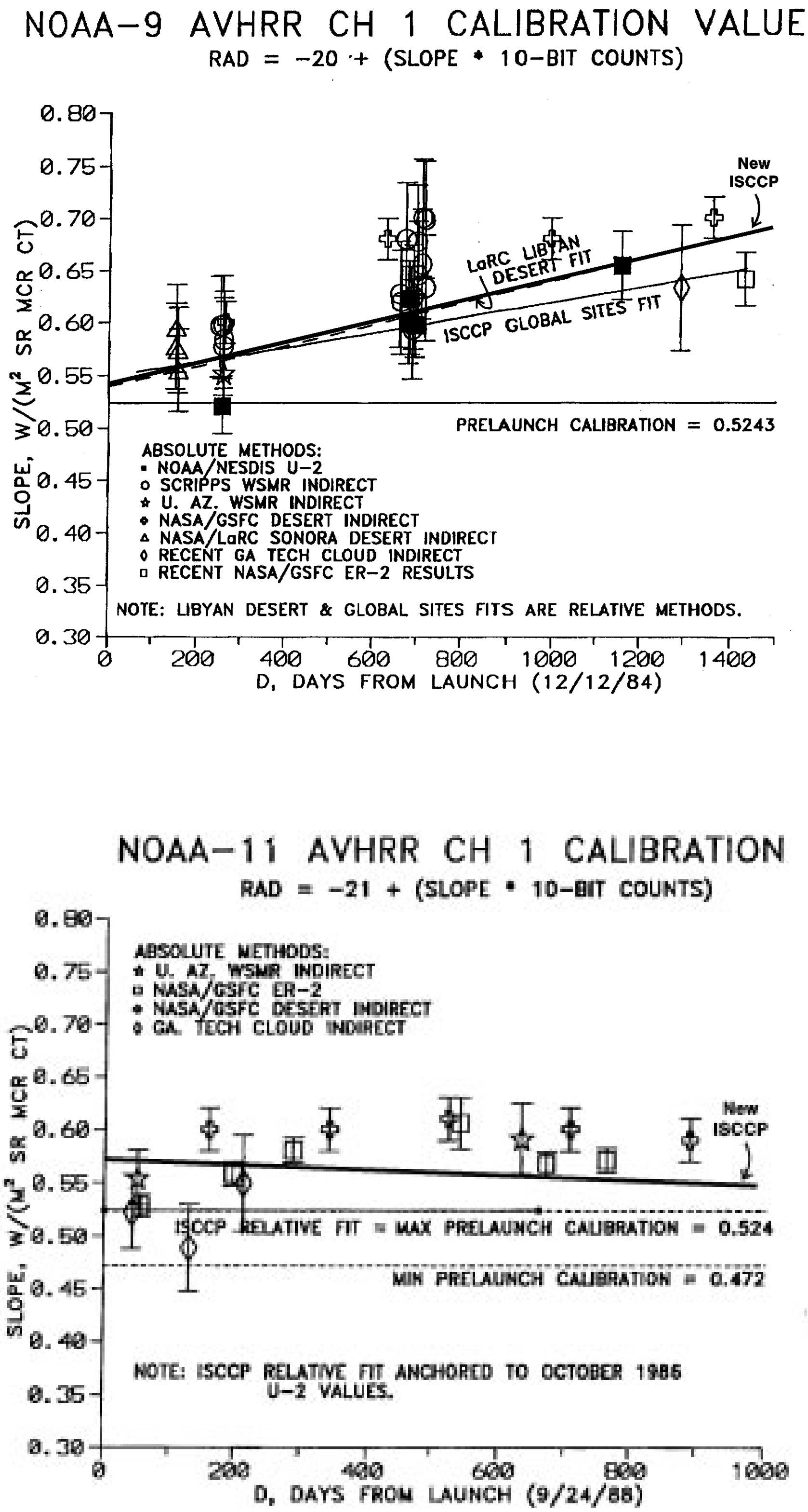

Figure 3. Various calibration results for AVHRR Channel 1 (a) on NOAA-9 and (b) on NOAA-11 (after Whitlock et al. 1990). The thin solid line shows lthe first ISCCP calibration and the thick solid line shows the new calibratio.n.

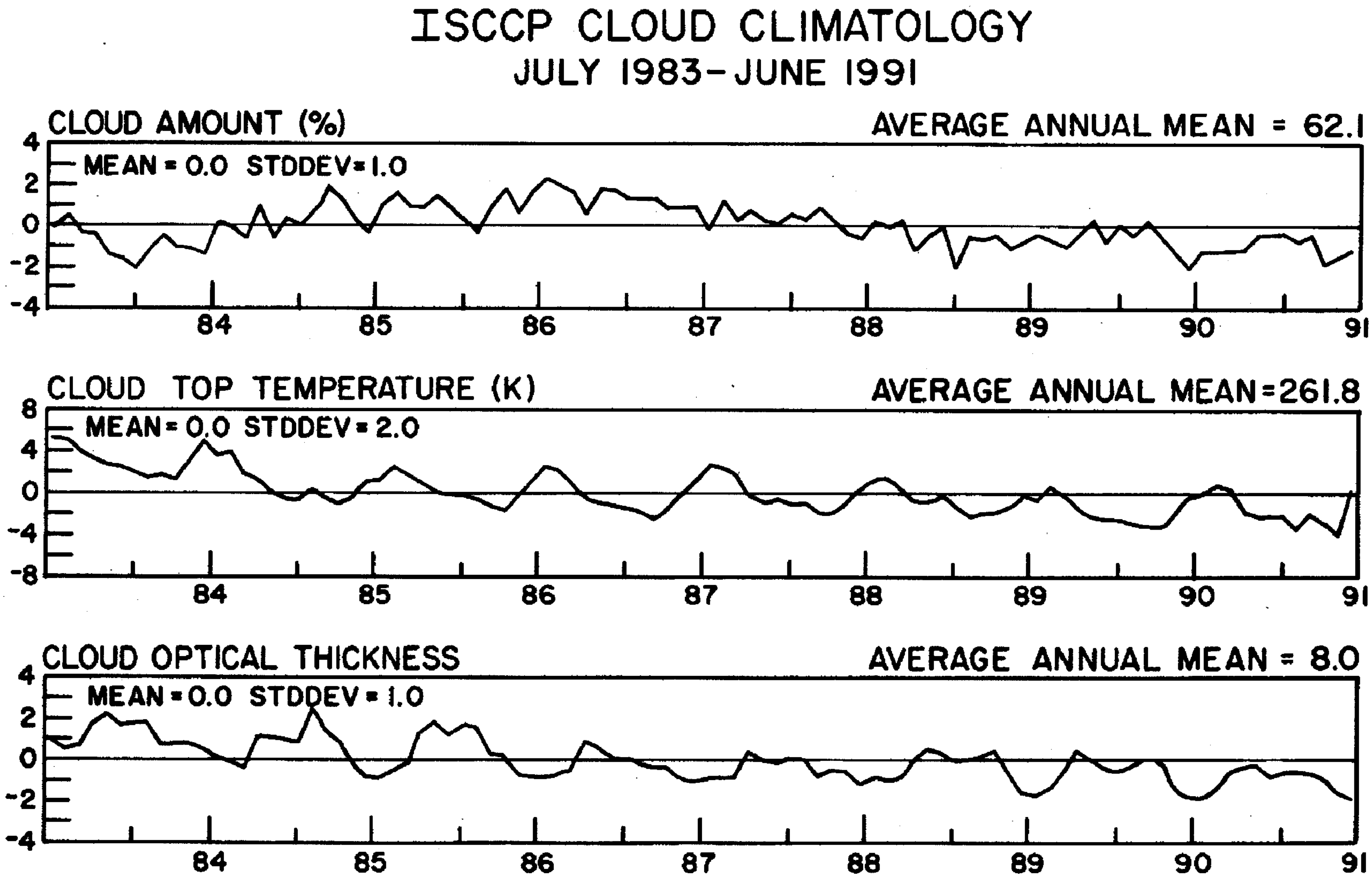

Figure 4. History of monthly global anomalies is total cloud amount, cloud top temperature and cloud optical thickness from ISCCP over the period July 1983 through June 1991. Global mean values are indicated. The trends in cloud top temperature and optical thickness are caused, in part, by radiance calibration offsets between the reference AVHRRs.

3. CHANGES TO GEOSTATIONARY NORMALIZATION PROCEDURES

The original analysis of the Stage B3 radiances produced the Stage CX dataset for each satellite. These results were mapped to an equal-area grid and various statistics calculated to produce the Stage CS dataset for each satellite. The Stage C1 dataset is then created from the several CS datasets by choosing observations for each map grid cell from one satellite among all available satellites that have satellite zenith angles $< 72.5^{\circ}$. As part of this process, observations from all different pairs of satellites are compared and the differences between their overlapped observations of surface and cloud top temperature, surface visible reflectance and cloud optical thickness are each collected into frequency histograms for each month. Corrections are calculated and applied to the monthly mean cloud dataset (Stage C2) to remove any offsets that are systematic for both quantities retrieved from the same spectral channel (VIS or IR). For each quantity the mode difference is calculated as the average of the mode and values in three intervals on each side of the mode value. Then the mode differences for the surface and cloud top temperatures are averaged to obtain the IR offset and for the surface visible reflectance and the cloud optical thickness (expressed in reflectance units) to obtain the VIS offset. Figure 1 shows the 8-year history of the modal differences between each geostationary satellite and the standard afternoon polar orbiter from the first analysis of the data.

In the revised procedure, the offset corrections applied to the C2 dataset in the previous analysis are used to determine additive offsets, if they exceed a threshold, that are applied directly to the Stage B3 radiances before re-processing. In the case of new data that have not been previously analyzed (beyond June 1991), the statistics shown in Figure 1 are monitored during the first processing: if any cases exceed the offset thresholds, then radiance calibration adjustments are calculated, as described below, and the whole dataset is re-processed. Thus, the major difference in the new procedure is that the calibration offsets determined **after** cloud analysis are used to modify the B3 radiance calibrations directly, rather than correcting only the monthly mean products.

The visible channel correction is determined by averaging the modal differences for the surface reflectance and cloud optical thickness. If the absolute value of the average difference is > 0.02 (these quantities are expressed as a fraction of the instruments full response when viewing a surface that reflects all the radiation from an overhead sun at the mean sun-Earth distance) and the surface reflectance difference is > 0.02, then an adjustment is determined as the smallest number of 0.01 increments that must be added or subtracted to reduce the difference below the threshold without making the surface reflectance < 0. The infrared channel correction is determined by averaging the modal differences for the surface temperature and cloud top temperature. If the absolute value of the average difference is > 1.0 K, then the adjustment is determined as the smallest number of 0.5 K increments that can be added or subtracted to reduce the difference below the threshold. Experiments were conducted using a variety of combinations of threshold values and adjustment increments; the above values were found to produce the best results as judged by avoiding a high frequency of essentially insignificant corrections and avoiding over-correction of the difference in mode values.

This procedure was checked in a set of experiments using selected months of data from several satellites where (1) known changes in the radiance calibrations were artificially introduced, (2) the whole month of data was processed through the entire ISCCP analysis, (3) calibration offsets were determined as described, (4) the adjustments were applied to the radiances, and (5) the dataset re-processed to check the magnitude of the remaining offsets. Figure 5 repeats a part of Figure 1 and shows the effect of the correction procedure (the needed corrections in this period are not very large). The lower panel in Figure 2 also shows that the artificial boundary between two adjacent geostationary fields of surface temperature is much reduced in the corrected version of the data. The procedure is conservative in that we do not eliminate the offsets entirely, rather we correct the calibration only enough to reduce the magnitude of the offset to below the threshold amounts. Thus, offsets up to 0.02 in VIS and up to 1.0 K in IR can remain. Any remaining offsets are still corrected in producing the monthly mean products, now called D2 data.

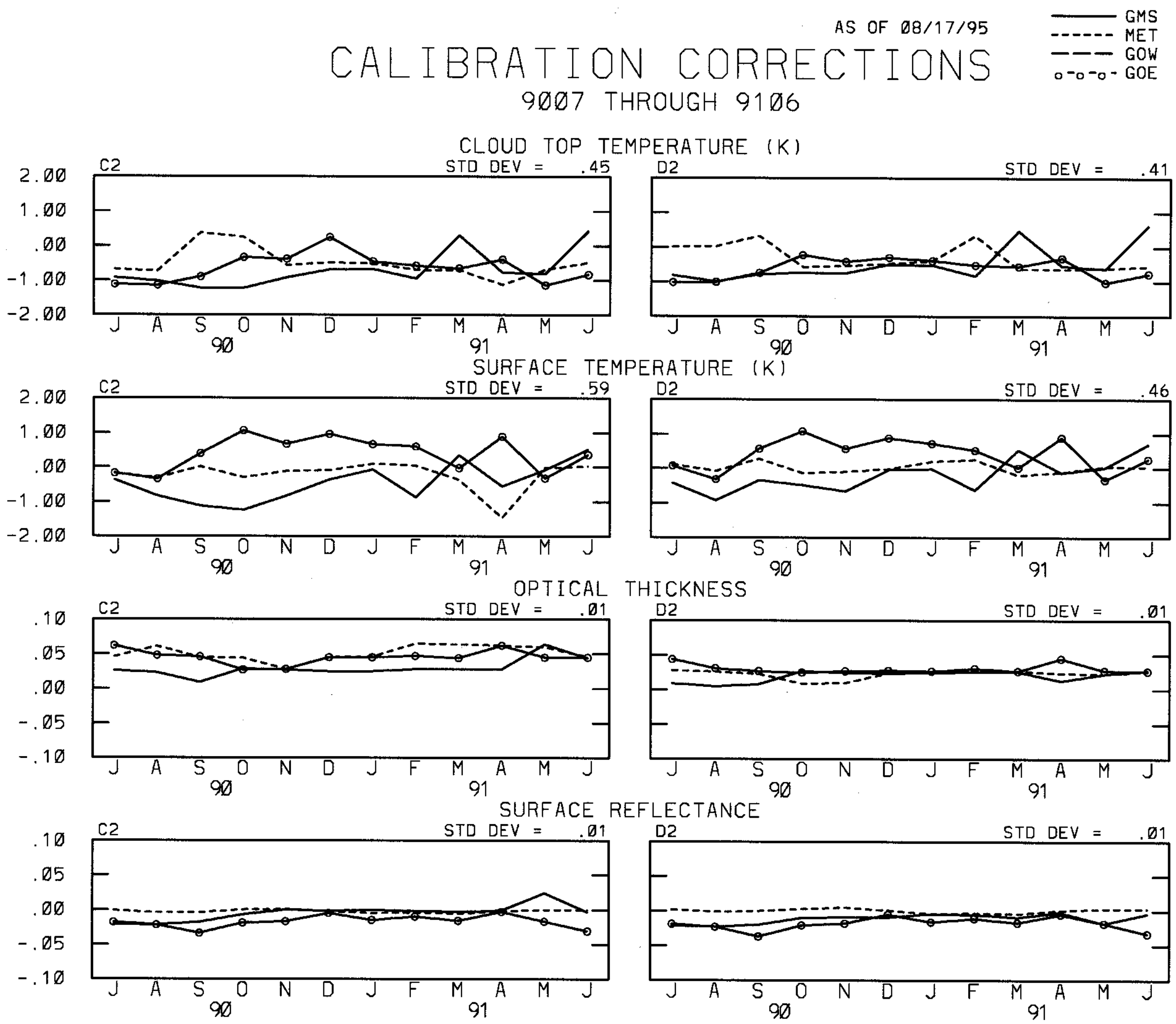

Figure 5. Repeat of the history of the modal differences shown in Figure 1 for the period July 1990 through June 1991, together with the same results after applying calibration corrections.

4. CHANGES TO POLAR ORBITER NORMALIZATION AND MONITORING PROCEDURES

4.1. Visible Radiances (AVHRR Channel 1)

A new normalization methodology (Brest et al. 1996, forthcoming) has been developed which uses NOAA-9 as the calibration reference standard (see next section). First, using the 4-year NOAA-9 record of monthly mean surface visible reflectances from the previous analysis, a 12-month climatology is produced as twelve global maps of surface reflectance with 0.5° resolution. This climatology is subtracted from each particular monthly mean map of surface reflectance from all satellites (e.g., January 1984 minus mean January, etc.). Global mean (and target mean) anomalies are calculated for each particular month and satellite from these anomaly maps. Second, the NOAA-9 record is corrected to remove a slight residual darkening trend, improving the agreement with trends determined by Staylor (1990) and from the aircraft measurements (cf., Figure 3a). Third, the absolute calibration for NOAA-9 is obtained by comparison with an updated analysis of three aircraft measurements made in October 1986 (cf., Brest and Rossow 1992). Fourth, the other satellite records are de-trended individually in an iterative procedure by adjusting the trend correction factor applied to the monthly mean surface reflectances until a least squares linear fit to the whole record for that satellite has a slope as close to zero as possible with the 8-bit precision ($\approx$ 0.4%) of the original radiances. Finally, each satellite in the afternoon series (NOAA-7, NOAA-11) and the morning series (NOAA-8, NOAA-10, NOAA-12) is normalized to NOAA-9 in another iterative procedure by adjusting the corrections until a least squares linear fit to the entire data record has a slope as close to zero as possible. To avoid introducing spurious differences because of differing diurnal phases, the morning polar orbiters (NOAA-8, NOAA-10, NOAA-12) are also checked separately; however, no significant discrepancy was found (cf., Brest and Rossow 1992).

This whole process produces a single, long-term calibration record with no trends (Figure 6, lower panel). Figure 7 shows the change in the long-term reflectances for the Sahara desert. This figure also highlights a persistent mystery concerning the NOAA-11 calibration: for all other AVHRR's the calibration corrections obtained using all targets (global) and individual targets, like the Sahara, are consistent (cf., Figures 6 and 7), but is not the case for the NOAA-11 AVHRR. A possible interpretation of this fact is that the Sahara surface reflectance has changed.

In the new procedure, the time record of the global mean surface reflectance **anomalies** is used, rather than the global mean surface reflectances as in the first procedure. Directly using the reflectances, with their strong seasonal cycles, caused errors in the trends when partial seasons were included in the record (Brest and Rossow 1992). Moreover, the presence of the seasonal variations reduced sensitivity to small changes in calibration. Thus, the new method is more sensitive and can be applied to any length time record, whereas the old method required at least one complete seasonal cycle. The quality of the final calibration record also depends on de-trending individual satellite records **before** combining them with the other satellites because, when using a linear fit procedure, a combination of line segments with non-zero slopes can produce an overall fit with zero slope. The key assumption is that, on average, the global anomalies of surface reflectances are zero over the whole record: this assumption could not have been made at the beginning of the data analysis but can now be made retrospectively. In effect, we have found that Earth is a radiometric target that is generally more stable than the satellite radiometers.

The eruption of the Mt. Pinatubo volcano on 12 June 1991 is the one exception to this stability in the current dataset: the uncertainty in Earth's reflectance introduced by variations of volcanic aerosol optical thickness precluded reliable monitoring of calibration for a time. Though the aerosol effect is barely discernable in the larger seasonal variations of the global mean surface reflectances, the anomaly of surface reflectances in a zone near the equator ($\pm$ 20° latitude) shows a significant effect (Figure 8). The period affected by the volcanic aerosol was judged to last until the end of 1992 because the anomalies of tropical surface reflectances measured by NOAA-11 in 1993 fell on the trend of values projected from the NOAA-11 record preceding the volcanic eruption. Thus, the de-trending of the NOAA-11 calibration was performed excluding data from July 1991 through December 1992. Various estimates of the aerosol optical thickness suggest a return to near-normal values in mid-1993 (McCormick and Veiga 1992, Kaufman 1995).

4.2. Infrared Radiances (AVHRR Channel 4)

IR calibration monitoring uses the distribution of brightness temperatures over all ocean areas aggregated over week-long periods: monthly averages of the 10th and 90th percentile temperatures (approximately 290K and 240K, respectively) are examined for trends or sudden deviations. In the old (first) calibration, no long-term trends were detected for individual radiometers, but normalizations of the IR calibration subsequent to October 1987 were required to eliminate the effects of a change in the NOAA operational IR calibration procedure introduced at this time. Subsequent studies of methods for correcting for small non-linearities in the AVHRR IR channel responses (see Section 5.3) show that the newer NOAA procedure was less accurate than the older NOAA procedure. The new ISCCP IR calibration monitoring procedure employs a technique similar to the visible calibration procedure to eliminate any trends and to normalize all other AVHRRs on polar orbiting satellites to the first three years of brightness temperatures from the AVHRR on NOAA-9 (calibrated with the older procedure). The time records of monthly mean 10th and 90th percentile values are fit by straight lines to search for trends. Slight trends (< 0.5% per year) were found for some 90th percentile values; but since no systematic trends for **both** 10th and 90th percentile values were found, no corrections were made. Then each record is converted into monthly mean anomalies by reference to the NOAA-9 mean annual cycle. Offsets between the least squares linear fits to each satellite record of 10th and 90th percentile temperatures with respect to NOAA-9 are used to calculate multiplicative and additive coefficients that provide a linear correction of the IR calibrations for each satellite. Figure 9 shows the corrected time records of the 10th and 90th percentile brightness temperatures.

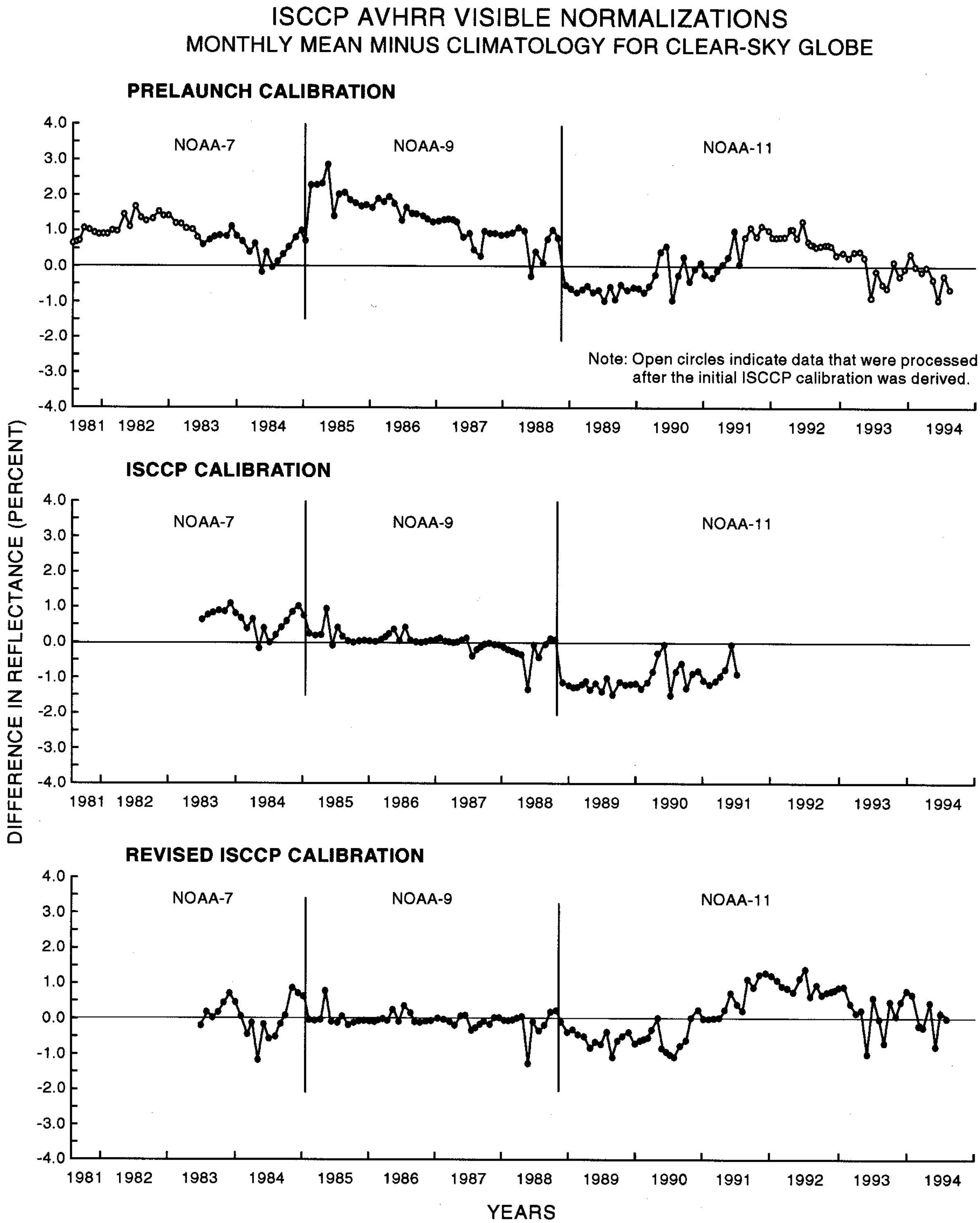

Figure 6. Global monthly mean anomalies of surface visible reflectances obtained from AVHRR on the indicated polar orbiters with respect to a monthly climatology based on the NOAA-9 results with the first ISCCP calibration. The upper panel shows results using the original calibration, the middle panel shows the old (first) ISCCP calibration, and the lower panel shows the new (revised) ISCCP calibration.

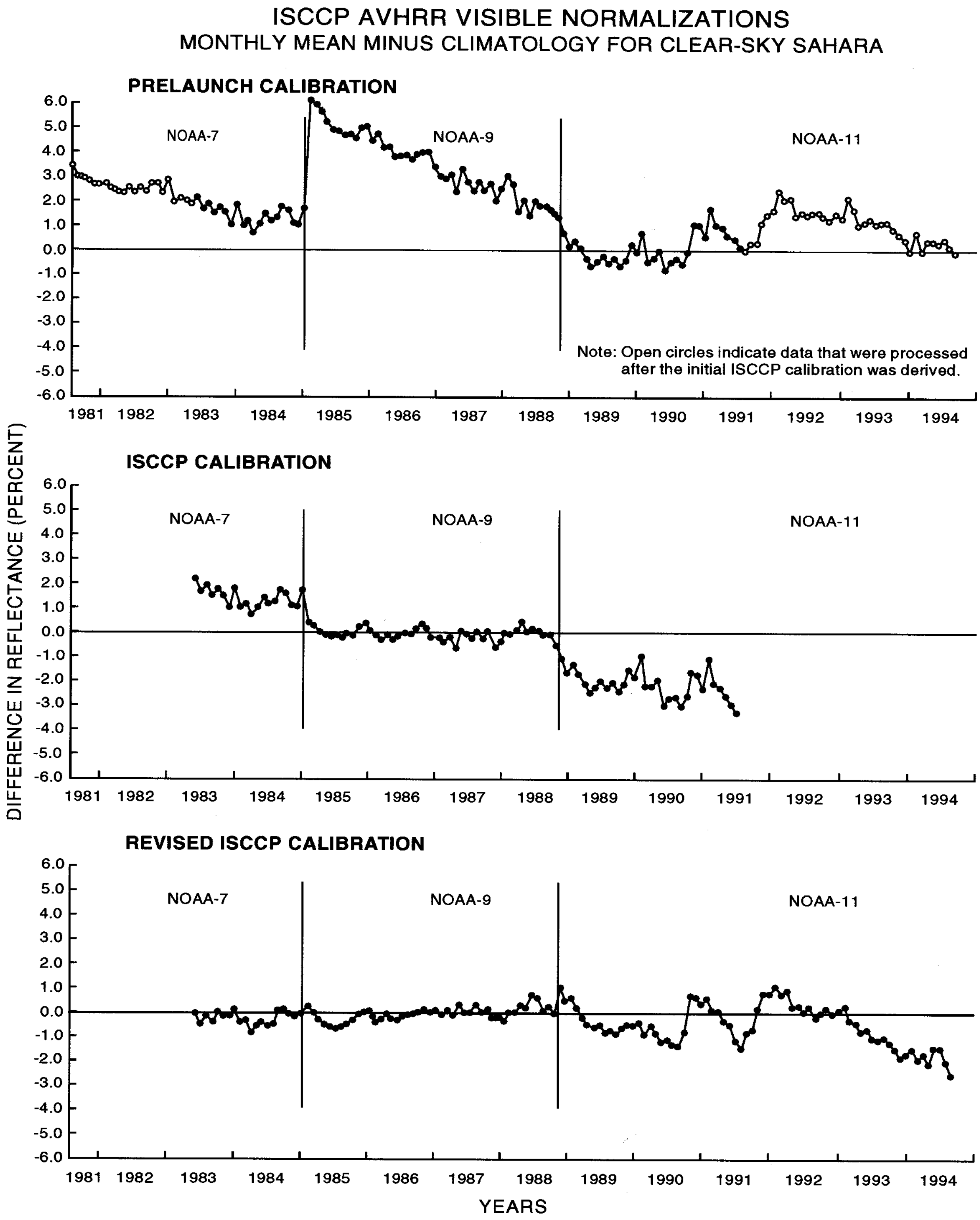

Figure 7. Time records of reflectances for Sahara.

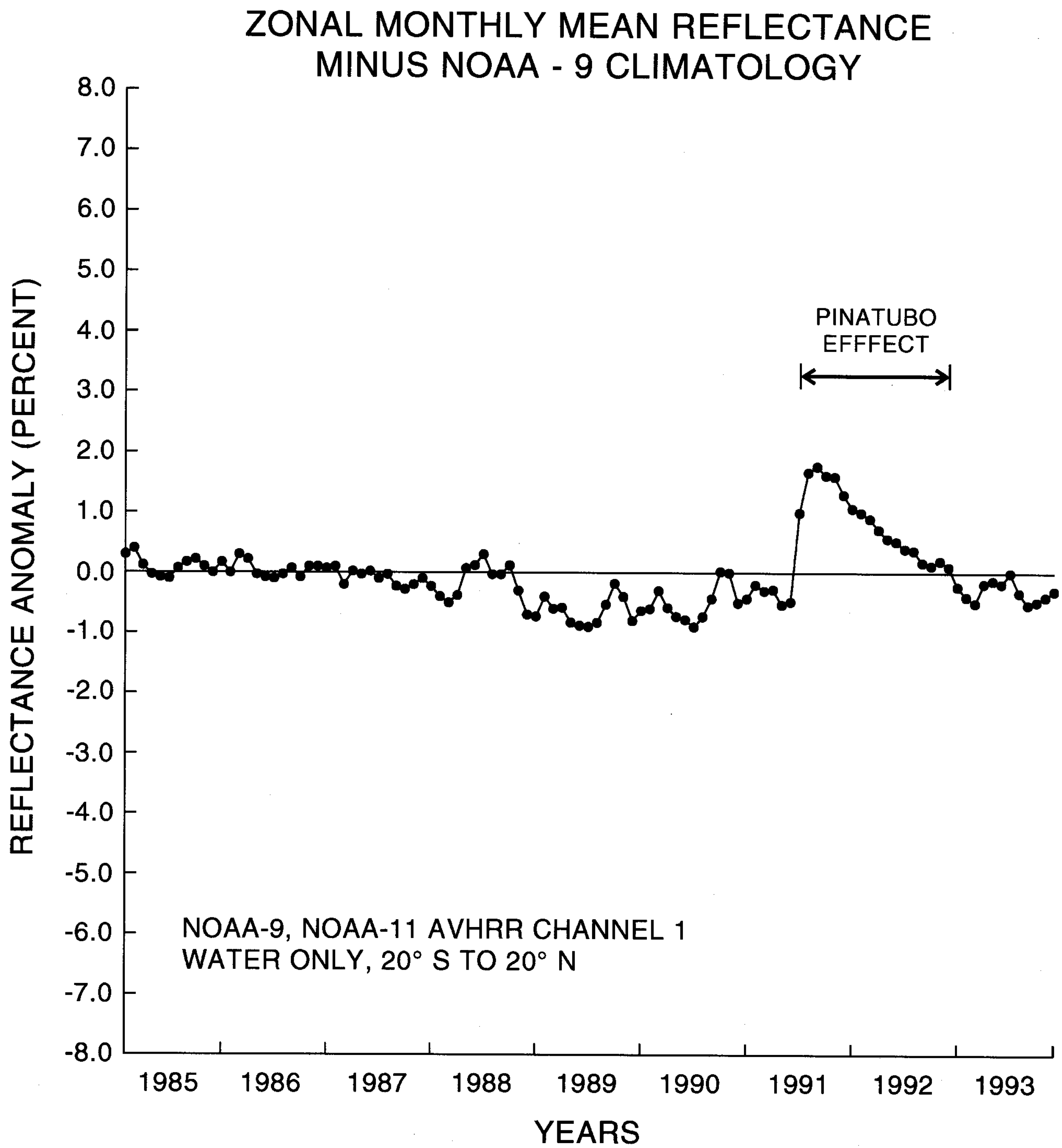

Figure 8. Anomaly record for tropics showing Pinatubo effect. These results use the old ISCCP calibration.

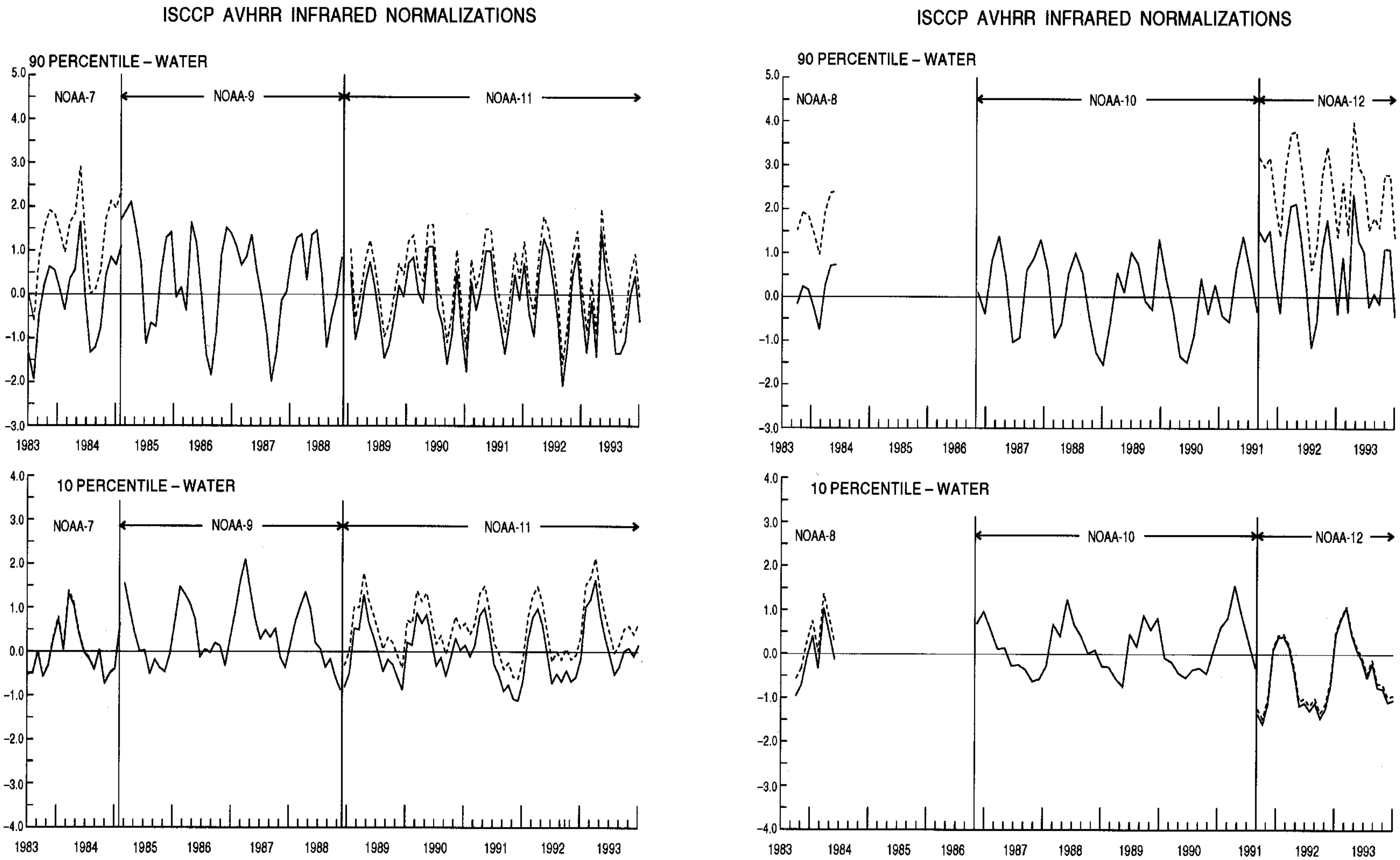

Figure 9. Monthly anomalies of the 90th (cold) and 10th (warm) percentile brightness temperatures obtained from global ocean distributions of individual measurements from AVHRR on the indicated polar orbiters, (a) afternoon series and (b) morning series. The anomalies are calculated relative to a monthly climatology based on NOAA-9. The dased lines indicate the original calibration and the solid lines indicate the new ISCCP calibration. The change in NOAA-9 calibration in October 1987 has already been removed.

5. CHANGES TO ABSOLUTE CALIBRATIONS

5.1. Shift to NOAA-9 Reference Standard

The studies of AVHRR calibration conducted by ISCCP (Brest and Rossow 1992, Desormeaux et al. 1993), by the Surface Radiation Budget project of the World Climate Research Program (Whitlock et al. 1990), and by the NASA-NOAA Pathfinder program (Rao et al. 1993a, 1993b) provide the most detailed and best documented information for the NOAA-9 and NOAA-11 AVHRRs. Since there are still some small discrepancies in the results of these studies, in the aircraft calibrations, and in other information concerning the NOAA-11 instrument, the NOAA-9 instrument was chosen to be the calibration reference standard for the AVHRR Pathfinder program and for the new version of the ISCCP radiance data. Henceforth, all ISCCP radiances will be normalized to this standard.

5.2. Change of Aircraft Visible Calibration for NOAA-9

As reported in Brest and Rossow (1992), the visible radiance calibration coefficients for the NOAA-9 AVHRR derived from three aircraft flights in October 1986 were revised slightly after the first ISCCP calibration was determined. The new calibration coefficients used for the revised ISCCP calibration are:

$$L\dagger = 0.004667\ (CT_8) - 0.04236$$

where $L\dagger$ is a value from zero to one and CT_8 = 0-255 (cf., Rossow et al. 1992).

Note that in the previous analysis, the visible calibration given in the Stage B3 dataset had to be multiplied by a factor of 1.2 to adjust to the first aircraft calibration. After the slight revision of the trend over the whole NOAA-9 record and the small revision of the aircraft calibration, this correction factor became 1.192. This factor is now **included** in the new calibration tables.

5.3. NOAA-9 IR Calibration

The response of the AVHRR IR channels is slightly non-linear, but the on-board calibration measurements only monitor instrument response at two temperatures, cold space and a "hot" reference target. Hence, the operational calibration procedure effectively assumes a linear response. During the first four years of ISCCP, the small non-linearity was partially accounted for in the NOAA operational calibration procedure by allowing the radiance associated with cold space to be negative thereby providing a better linear fit to the non-linear response function. However, beginning in October 1987, this procedure was discontinued in favor of a different approach. To maintain the consistency of the ISCCP radiance dataset, IR brightness temperatures after this date were normalized to values before this date. Pathfinder studies (Rao et al. 1993a) have developed a more accurate procedure to correct for the non-linear response; however, its application requires use of the time history of the on-board calibration target temperature for best results. Without this detailed history, the correction procedure can be employed with an estimate of the target temperature, which produces results similar to the old operational method. Comparisons of retrieved values of sea surface temperatures (Rossow and Garder 1993) and total infrared fluxes at the top of the atmosphere calculated from the retrieved cloud top temperatures (Rossow and Zhang 1995) during the NOAA-9 period (February 1985 - October 1988) suggest that the absolute IR calibration is accurate to within $\pm$ 1.5K. Hence, we have not applied the new Pathfinder correction procedure (because we lack the detailed history information). Instead we normalize all other AVHRR IR radiances to the NOAA-9 values calibrated by the old NOAA procedure as the reference standard.

5.4. Other Calibration Changes

In the previous calibration report (Rossow et al. 1992), the given values of the effective solar spectral irradiance for NOAA-12 and METEOSAT-5 are incorrect. In Table 2.2 on page 6, the values of E_{o1}/π and E_{o2}/π for NOAA-12 should be 63.86 and 73.22 watts m^{-2} sr^{-1}, respectively (instead of 63.43 and 83.13 watts m^{-2} sr^{-1}). On page 38, the value of E_o/π for METEOSAT-5 should be 184.56 watts m^{-2} sr^{-1} (instead of 197.71 watts m^{-2} sr^{-1}). These errors did not affect the scaled radiance tables used in the ISCCP analysis, but only affected the tables that convert VIS count values into radiances with units of watts m^{-2} sr^{-1}.

In the first processing of NOAA-10 radiances, an incorrect bandwidth value was used in calculating the calibration of the IR channel from December 1986 through December 1988. When the bandwidth was corrected, the normalization coefficients were also changed in January 1989 to preserve proper relative calibration. In the second version of the NOAA-10 calibration, the correct bandwidth is used throughout; consequently there is no change in the IR normalization coefficients in January 1989.

Beginning in 1996 and up to March 4th of the same year, the GOES original radiance counts for the infrared channels are coded in 10 bits; for the ISCCP B2 and B3 radiance datasets, these counts are re-coded to 8 bits using a conversion table to provide a radiance scale approximately linear in energy. For GOES-8 and subsequent satellites, the original radiance counts are already nearly linear in energy, so the re-coding of the radiances for the ISCCP B2 and B3 data simply involved dividing the original count values by four. However, in the B2 data provided by CSU for GOES-8/9, the Water Vapor channel (6.7 μm nominal wavelength) counts were divided only by two to expand the dynamic range, whereas in the GOES-8 data provided by MSC (formerly AES), the original radiances are divided by four. After March 4, 1996, the ISCCP B3 data for GOES-9 and GOES-10 was produced by dividing all water vapor channel counts by 2.5.

Starting with NOAA-15 and continuing with subsequent satellites, a revised model AVHRR is flown that has six wavelength channels: The additional wavelength is 1.6 μm (nominal). However, the AVHRR Global Area Coverage (GAC) format continues to provide space for only five wavelength channels. Consequently, the radiances for this channel (Channel 3 in GAC format, Channel 4 in ISCCP B3 format) were planned to switch between the 1.6 μm channel on the "day" portion of the orbit and the 3.7 μm channel on the "night" portion of the orbit. This feature was not activated for NOAA-15, but is active on subsequent satellites. However, inspection of the NOAA-15 data showed that the AVHRR occasionally switched channels from 3.7 μm to 1.6 μm and back again, but the on-board calibration information continued to be for the longer wavelength; this situation was always indicated by the channel switch flag and a "bad calibration" flag in the data. In the ISCCP B3 format for NOAA-15, this channel is assumed to be the 3.7 μm channel always (as for all previous AVHRR data), thus the improperly switched data are discarded (replaced by "no-data").

6. CALIBRATION (STAGE BT) DATASETS

To make it easier to change the calibration of the Stage B3 radiance dataset without having to reprocess hundreds of data tapes for each year, a new Stage BT dataset has been created to report the calibration for every individual satellite image in the Stage B3 dataset. This product consists of calibration look-up tables to convert radiance count values to physical radiance units for each image that has been processed into B3 format. Only images which have actually been processed by ISCCP have calibration tables included. As a reference, Version 0 of this dataset, available only for data prior to July 1991, presents the original Stage B3 calibration **without** the final correction factor of 1.2 applied to visible radiances (ie., exactly the same look-up tables as are found on B3 data tapes). Version 1, available for data from July 1983 onwards, contains the new calibration that resulted from the re-analysis described above, **including** the final absolute adjustment factor of 1.192 for the visible radiances. There is no Version 0 BT dataset after June 1991. Any other changes or corrections of calibration will be reflected by higher version numbers: the best calibration is always by the BT dataset with the highest available version number.

The BT dataset reports the results of the ISCCP calibration procedures in the same form as in the Stage B3 dataset: tables are provided for each satellite image that list the physical radiance values for each radiance count value (0 - 254, 255 is reserved to indicate no data). If a B3 image does not exist at a particular time, then no BT tables are reported for that time. A B3 image may have radiances for up to five spectral channels, depending on the satellite. The number of calibration tables varies accordingly and is indicated in the header record for each time. For each channel available, there are six calibration tables reported. They are Nominal Radiance, Normalized Radiance, Absolute Radiance, Nominal Scaled Radiance (VIS) or Brightness Temperature (IR), Normalized Scaled Radiance (VIS) or Brightness Temperature (IR), and Absolute Scaled Radiance (VIS) or Brightness Temperature (IR). The Absolute tables represent the best available calibration information used by ISCCP. *Note that the ISCCP calibration corrections are obtained only for the standard wavelengths, VIS ≈ 0.6 μm and IR ≈ 11 μm. For other spectral channels, only the Nominal calibration is reported in all six tables.* Those channels that measure reflected sunlight have no calibration information for the "nighttime" geostationary images, defined as the three time slots centered on local midnight. If a particular channel is unavailable, then only the header record is present with no tables reported. Each Stage BT data file contains all the calibration tables from one volume of Stage B3 data, representing either 8 days (polar orbiters) or 16 days (geostationary) of data. Each BT volume (3480 cartridges = 200 Mbytes) contains about six months of polar orbiter calibrations or about 20 months of geostationary calibrations.

For the visible channels, counts are converted either into radiances in units of watts m^{-2} sr^{-1}, representing the energy intercepted by the instrument, or scaled radiances, normalized to the amount of energy received by the instrument when viewing a surface with unit albedo illuminated by the sun at the mean sun-earth distance. For infrared channels, counts are converted either into radiances or into brightness temperatures, which represent the intercepted energy in terms of the temperature of a blackbody that emits the same amount of energy. The Nominal tables use the original operational calibration available for each radiometer (Rossow et al. 1992). The Normalized and Absolute tables are slightly different for polar orbiters and geostationary satellites. For geostationary satellites the Normalized tables report the SCC-determined normalization to the reference AVHRR, whichever one is operating at that time, and the Absolute tables account for trends in the calibration of the reference AVHRR, for offsets between the particular AVHRR and the NOAA-9 AVHRR, and include any short-term corrections determined by the GPC. Any corrections obtained from the revised calibration analysis, described above, are also included in the Absolute tables. For the polar orbiters, the Normalized tables include the old (first) version of both the Normalized and Absolute calibration adjustments, plus the new normalization of the particular AVHRR to the NOAA-9 AVHRR. The Absolute tables provide the trend correction of the particular satellite (as adjustments to the first version) and the final adjustment of the NOAA-9 calibration to aircraft calibration flights. The calibrations provided in the Absolute tables are used in the ISCCP cloud analysis.

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