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VISIBLE AND NEAR-INFRARED CHANNEL CALIBRATION OF THE GOES-6 VISSR USING HIGH-ALTITUDE AIRCRAFT MEASUREMENTS

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SUMMARY

Present and future visible and near-infrared wavelength sensors mounted on operational satellites do not have on-board absolute calibration devices. One means of establishing an in-orbit calibration for a satellite sensor is to make simultaneous measurements of a bright, relatively uniform scene along the satellite view vector from a calibrated instrument on board a high altitude aircraft. In the work reported here, aircraft data were recorded over White Sands, New Mexico, and comparison of the coincident aircraft and orbiting satellite data is discussed for the visible and near-infrared wavelength channel of the GOES-6 Visible Infrared Spin-Scan Radiometer.

INTRODUCTION

For long term studies of global trends to be feasible, the satellite data user community requires calibrated data products from the visible and near-infrared wavelength channels of the instruments aboard geostationary and polar orbiting satellites. The Visible-Infrared Spin-Scan Radiometer (VISSR) aboard the Geostationary Orbiting Environmental Satellite (GOES) series images an entire hemisphere of the globe once each hour in three spectral bands (700, 6700, and 11,000 nm) to provide near-global coverage for environmental observations of cloud cover, atmospheric water vapor and temperatures. Unfortunately, the VISSR has no on-board extended source calibration system for the visible and near-infrared band (700 nm); it is, therefore, limited in terms of making long term studies of global trends. Assuming a constant target, changes in the observed output of the solar channels of a satellite sensor are most likely to be a result of degradation of the larger foreoptics elements since they are directly exposed to the deteriorating effects of the space environment. Changes in the electronic gain or in detector sensitivity also would alter the output level of the sensor. The best on-board calibration system would be one that monitored instrument performance utilizing the full optical field of view and all elements of the optical system. An alternative to on-board calibration is the comparison of satellite data to calibrated high-altitude aircraft measurements using bright, relatively uniform target areas on Earth such as White Sands, New Mexico. Simultaneous clear-sky satellite and aircraft measurements are made along the satellite view vector, using a calibrated instrument on-board a high altitude aircraft. The effects of the atmosphere are for the most part empirically included using this method, and the aircraft measurement becomes a near duplicate of the satellite measurement. The aircraft radiance is corrected (see Correction for Atmosphere Above the Aircraft) for the small amount of atmosphere above the aircraft and then compared to the coincident, collocated satellite sensor radiance measurement based on prelaunch calibration. The results of this comparison characterize the in-orbit condition of the satellite sensor. A calibration table of in-orbit radiance versus counts can be produced.

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The White Sands, New Mexico area is a desirable surface calibration target because the probability for clear sky is great. Also, the characteristics of the atmosphere over the Sands have been well documented for a number of years by resident agencies and other experimenters. The reflectance of the surface of White Sands, New Mexico is considered to be near-Lambertian because the "grains" of sand are elongated, randomly oriented, flat, clear crystals of gypsum. The dunes that are present and the consequent sun shadowing do not seriously affect this characteristic of the surface. For calibration measurements, the use of a diffuse surface target such as White Sands is desirable. A diffuse target minimizes the error in the measurement produced by the solid angle difference between the field of view of the satellite instrument in orbit and the high altitude aircraft instrument. An additional advantage of White Sands is that its radiance lies in the higher dynamic range of the satellite instrument. The National Oceanic and Atmospheric Administration (NOAA) National Environmental Satellite, Data, and Information Service (NESDIS) has conducted several high altitude U-2 aircraft-satellite calibration missions over the White Sands area for the Advanced Very High Resolution Radiometer (AVHRR) on NOAA-9 (refs. 1 and 2) and the Landsat Thematic Mapper (ref. 3). A calibration (ref. 4) of the visible and near-infrared channels of the NIMBUS-7 Coastal Zone Color Scanner (CZCS) has also been accomplished by NESDIS using the method described above, but using the same aircraft instrument flown over ocean water.

SATELLITE INSTRUMENT CALIBRATION

Prelaunch calibration of the visible and near-infrared channels of a satellite instrument presents a problem because none of the radiance or irradiance calibration sources available from the National Bureau of Standards (NBS) fill the full aperture of the instrument. The best, most uniform extended visible source is an integrating sphere (ref. 5) internally illuminated by a series of quartz halogen lamps and painted white with barium sulfate. Sphere sources can be made large enough to fill the aperture of the satellite instrument. However, the NBS does not maintain or supply data for sphere sources. The NOAA/NESDIS 1.07-m-diam sphere source (ref. 5) was used to calibrate the aircraft instrument just prior to, and immediately following, aircraft data gathering missions. A similar sphere source, supplied by NASA Goddard Space Flight Center (GSFC), was used by the GOES-6 satellite instrument vendor to provide a prelaunch calibration. The GSFC and NESDIS sphere sources were both calibrated by the same commercial facility whose source is NBS calibrated. This common traceability of calibration to NBS is illustrated in figure 1.

FIELD MISSION

A NESDIS aircraft data-gathering field mission is illustrated in figure 2. Not all of the measurements illustrated in figure 2 were conducted during a specific field mission. In October 1986, data were gathered from the U-2 over White Sands in the view vector of the GOES-6 VISSR. The NASA Ames U-2 aircraft was flown out of Moffett Field, California.

AIRCRAFT INSTRUMENT

The NESDIS U-2 instrument was a visible and near-infrared wavelength, 1/8-m focal length Ebert, rapid scanning grating double monochromator (ref. 6) previously flown on the NASA Learjet. The

U-2 instrument produces output in counts which are calibrated in radiance. This instrument has seen extensive aircraft usage since 1982 and its reliability and stability have been well documented by NOAA from many laboratory, field site, and in-flight sphere source-calibration measurements. The repeatability of measurement with the instrument is $\pm 0.5\%$. The nadir footprint (field of view) of the aircraft instrument is about 2.5×2.5 km for the U-2 at 19.8 km altitude.

VISSR DATA

The current VISSR system uses eight redundant bandpass channels with eight photomultiplier detectors, each having an approximate 1×1 -km-surface instantaneous field of view at nadir on the equator. Each scan sweep consists of all eight detectors and is therefore 8 km in height. The bandpass of the VISSR is approximately 500 to 900 nanometers (nm) and is provided by eight individual optical filters placed in front of the eight detectors. There is a spread of 8% in the half-power bandwidth of these eight filters. In the GOES-6 VISSR, the channel 6 bandpass is representative of the average of all eight channels. The channel 6 bandpass shown in figure 3 was used in this report for the calculation of bandpass radiance. It is not possible to fabricate photomultiplier detectors or optical filters that have identical characteristics. For this reason, the output of the eight VISSR channels could be nonuniform (striped) when viewing a uniform surface; hence, the characteristic "striping" that occurs in the VISSR output. "Destriping" of the VISSR data takes place at the ground readout station by means of a data processing unit called the synchronous data buffer (SDB). In simple terms, the SDB adjusts the individual channel gain of each channel of the raw VISSR signal to produce a uniform output level. This process is called normalization and this ground-station generated data are those which are distributed to the users.

The VISSR full-Earth disc images are generated at half-hour intervals. During the half-hour that the U-2 aircraft data were gathered, the Satellite Operations Control Center provided 1:1 ratio SDB data or the raw VISSR data. These raw VISSR data are those which were used to compare to the concurrent, calibrated aircraft instrument data. The VISSR six-bit digital system limits the information exchange of the voltage output to digital-counts conversion (fig. 4). The slope of the VISSR output is a variable and is divided into five individual increments, as shown in figure 4 which outlines the VISSR volts to digital-count calibration slopes. Figure 4 is necessarily composed of five separate slopes. A small change in the near-zero output volts produces a greater count change than that at higher voltages. At the vendor facility, all eight channels are currently calibrated to albedo rather than radiance using the solar constant values of Thekakara et al. The albedo versus volt calibration data are the only data provided to the user community, and are given for three instrument temperature ranges: 0°C , $+15^\circ\text{C}$, and $+35^\circ\text{C}$. These data cannot be directly compared to the U-2 aircraft instrument data which produce calibrated radiance output. It is necessary to convert the VISSR prelaunch albedo calibration to radiance. The radiance-versus-count GOES-6 VISSR prelaunch calibration (fig. 5) was generated with the same solar constant values originally used by the vendor. A comparison could then be made between the VISSR radiance and the aircraft measured radiance. No significant changes have been observed in the VISSR zero-count level.

AIRCRAFT DATA—VISSR CALIBRATION

The U-2 instrument scans the visible and near-infrared wavelength region from 400 to 1050 nm or 0.400 to 1.050 μm . A typical 10-sec spectral scan of U-2 aircraft instrument data is shown in figure 6. The visible and near-infrared spectrum of White Sands is shown with the VISSR spectral response from

figure 3. Aircraft radiance is calculated as a convolution of the aircraft instrument spectrum with the figure 3 VISSR spectral response function. The aircraft measured, calculated radiance is typical of that measured by the satellite instrument. As mentioned earlier, the VISSR bandpass shown in figure 6 is that of channel 6 and represents an average of all eight channels. Channel 6 bandpass is used for all calculations in this report. A comparison was made of the radiance in the bandpass of VISSR channel 1, channel 6, and channel 8 using the White Sands spectrum of figure 6. This comparison indicated a 1% spread in the three radiance values, which is within the 5% experimental accuracy of measurement. A typical White Sands sector of VISSR satellite data from October 25, 1986 is shown in figure 7. The White Sands Dunes area is outlined in figure 7 and the satellite data field is in radiance units of $\text{mW}/[\text{cm}^2 * \text{sr} * \mu\text{m}]$.

Correction of the aircraft radiance for the effect of the 5% of the atmosphere above the aircraft is necessary. The aircraft radiance will then be equivalent to the surface radiance as viewed by the satellite instrument. This small correction was applied to the aircraft measured radiance and is discussed in the section Correction for Atmosphere Above the Aircraft. Each figure 7 numerical data point represents the average satellite radiance of a 3×3 -km area. Thus, the satellite data correlate to the 2.5×2.5 -km aircraft data footprint. The figure 7 numerical satellite data points outlined with a parallelogram are the area footprints of the aircraft data. The White Sands brightness is not uniform. A 10% variance in brightness from pixel to pixel can be observed in figure 7. This nonuniformity is put to advantage as a means to collocate the satellite and aircraft data. A plot of the aircraft footprint radiance (corrected for the atmosphere above the aircraft) versus ground location produces a brightness contour graph (fig. 8) of the aircraft data. Each parallel track of satellite pixels also produces a unique brightness contour. The computer searches the brightness contour of each parallel track of satellite data until it finds a track that matches the contour of the aircraft data. In the entire satellite data field of figure 7, one track of data is found that has a brightness contour very similar to the aircraft data. The latitude-longitude data from both the aircraft and the satellite data sets could be used to collocate the data sets but this error is ± 1 km, whereas the contour fit error is ± 0.5 km.

Figure 8 shows a typical plot of radiance versus ground location for GOES-6 VISSR, along with the 65,000-ft altitude, U-2 aircraft measured radiance (corrected to the top of the atmosphere) in the VISSR bandpass at the same surface location. The White Sands aircraft data of October 25, 1986 fall in the dynamic range of the VISSR calibration slopes 3 and 4 of figure 4. It is therefore necessary to process the data separately for slopes 3 and 4. The calibrated aircraft data indicate a higher radiance than the VISSR prelaunch calibration. Collocated slope 3 data show that the aircraft radiance is 15.8% higher than the VISSR prelaunch. Slope 4 data show that the aircraft radiance is 13.2% higher than the VISSR prelaunch. Figure 9 is a plot of radiance versus counts, aircraft data, and VISSR prelaunch data.

The authors deem it better to work with the individual data of VISSR calibration slopes 3 and 4, rather than any type of averaging. Prelaunch and October 1986 radiance calibration coefficients have been generated and are summarized in the Results. The error of radiance calibration measurement (table 1) is $\pm 2.56\%$. An error bar of 5% should be applied to both the satellite prelaunch data and the U-2 aircraft data.

GROUND PARAMETER MEASUREMENTS

The field mission at White Sands, New Mexico included some of the ground measurements outlined in figure 2. No solar spectra were recorded coincident with the VISSR. Surface meteorological data, including horizontal visibility, are available for each day. Whenever possible, surface soil moisture

(ref. 7) and rawinsonde observation (RAOB) data to balloon burst were recorded, coincident with satellite overpass.

CORRECTION FOR ATMOSPHERE ABOVE THE AIRCRAFT

Empirical measurements of the zenith direction atmospheric transmission from space to 11.6 km altitude was made earlier by Arvesen (ref. 8) using calibrated instrumentation on board a high altitude aircraft. In his data set the atmospheric transmission was found to be above 0.99 for wavelengths larger than 1000 nm and greater than 0.9 for wavelengths larger than 410 nm. The Arvesen data show that the ozone band between 500 and 600 nm decreases the atmospheric transmittance less than 2%. The only other atmospheric absorption detected is the narrow oxygen band at 762 nm. The Arvesen data was extrapolated to the U-2 altitude of 19.2 km and the effect of the day-to-day variable satellite view vector was included. The residual error was estimated to be $\pm 0.2\%$. The path radiance contributed by the atmosphere above the aircraft to the satellite radiance was ignored because of the brightness of White Sands. An estimate of the worst case for this path radiance showed it would be less than 0.4% of the satellite radiance. Hence, the combined error in correcting for the atmosphere above the aircraft would be less than 0.5%.

RESULTS

Calibration coefficients have been generated for the data sets. Radiance can be calculated as a product of scene satellite counts minus the offset counts, and the calibration coefficient. The offset count for the GOES-6 VISSR calibration slope 3 is 10.6 and for slope 4 it is 14.8. In October 1986, the GOES-6 had been in orbit for 3 yr. A summary of calculated radiance calibration coefficients for the GOES-6 VISSR follows.

<u>Count Range</u>	<u>Prelaunch</u>	<u>October 1986</u>
16-24 (slope 3)	0.529	0.628
24-48 (slope 4)	0.765	0.880

CONCLUSIONS

The work reported in this paper demonstrates that the visible and near-infrared channels of satellite instruments may be effectively calibrated using high altitude aircraft data. Aircraft data gathered on a regular basis could produce a data set that would monitor the performance of the satellite instrument. This data set would be valuable to the satellite digital data user community and would provide validation for the atmospheric modeling community.

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TABLE 1.- RADIANCE CALIBRATION ERROR ANALYSIS

	Uncertainty
I. Primary Standard – NBS	
Wavelength (nm) 400-1050	±2%
II. Secondary NBS Standard-Optronic Laboratories, Inc. Transfer to 30 in. diam. sphere	±1.5%
III. Aircraft Spectrometer	
Wavelength determination	±0.2%
Electronic noise	±0.1%
IV. Data Analysis	
Correction for the atmosphere above the aircraft	±0.4%
Total radiance uncertainty	±2.56%

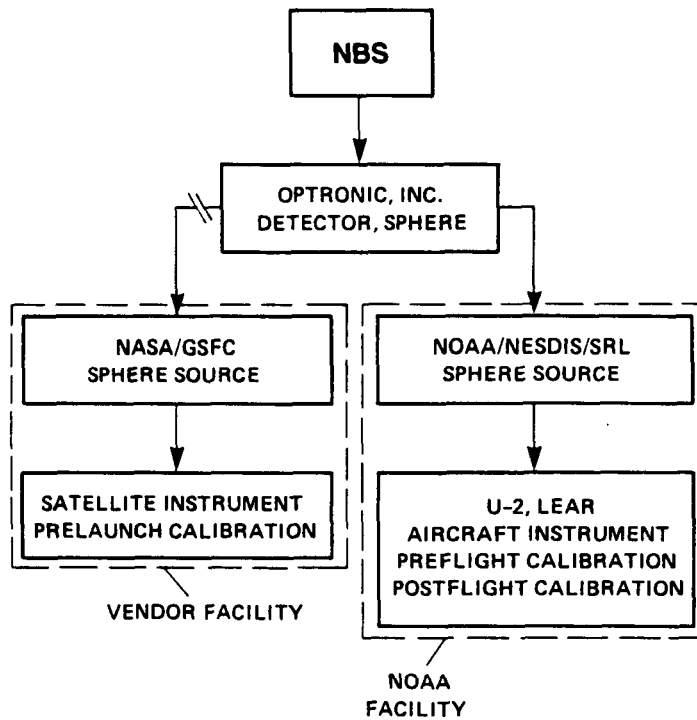
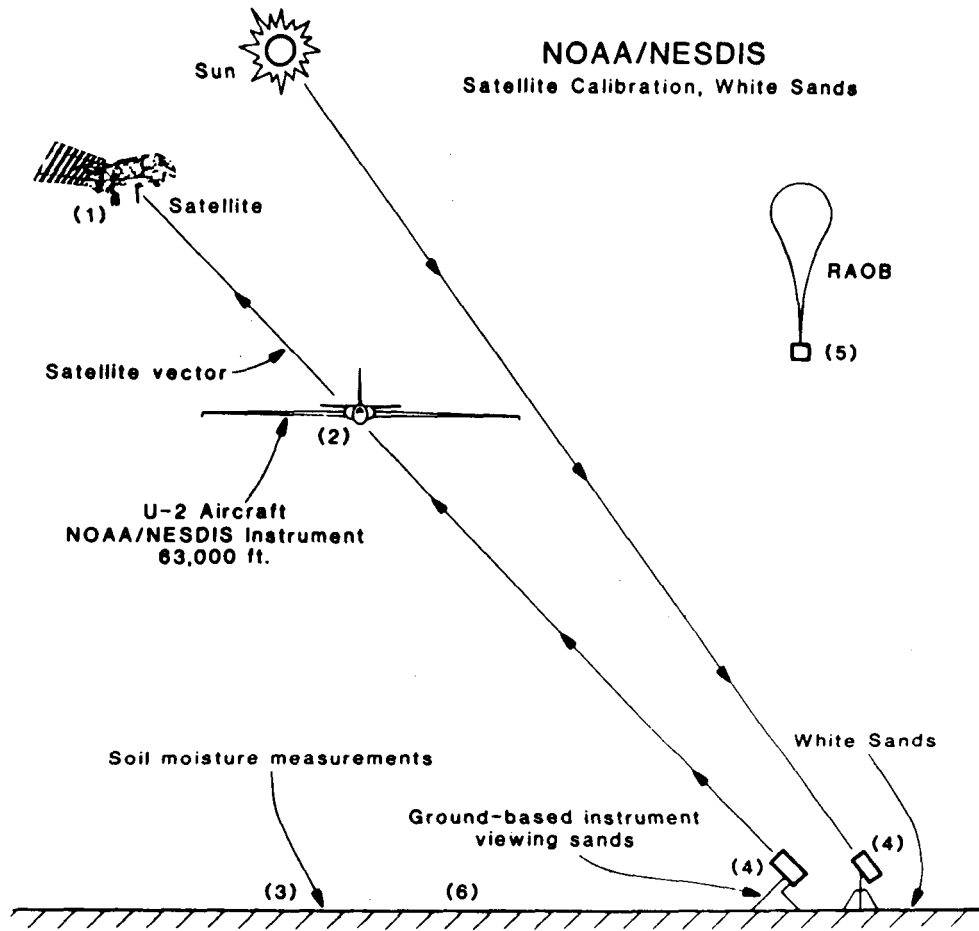


Figure 1.- NBS calibration traceability.



Simultaneous measurements :

- (1) Satellite Data
- (2) U-2 Aircraft Instrument Data
- (3) Soil moisture measurements
- (4) Solar Spectra, other Ground Truth measurements
- (5) RAOB Data
- (6) Local Surface Meteorological Data

Figure 2.- NESDIS aircraft mission.

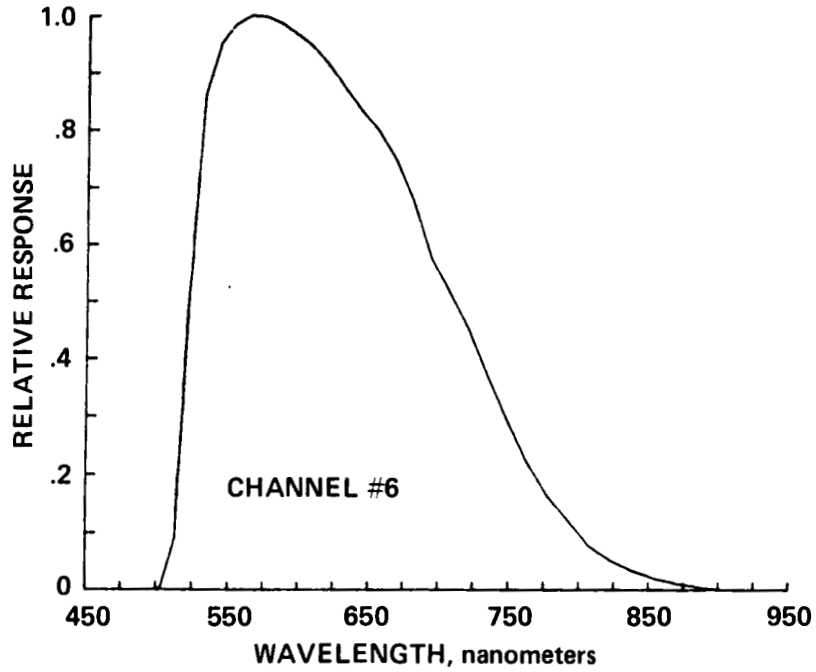


Figure 3.- VISSR bandpass.

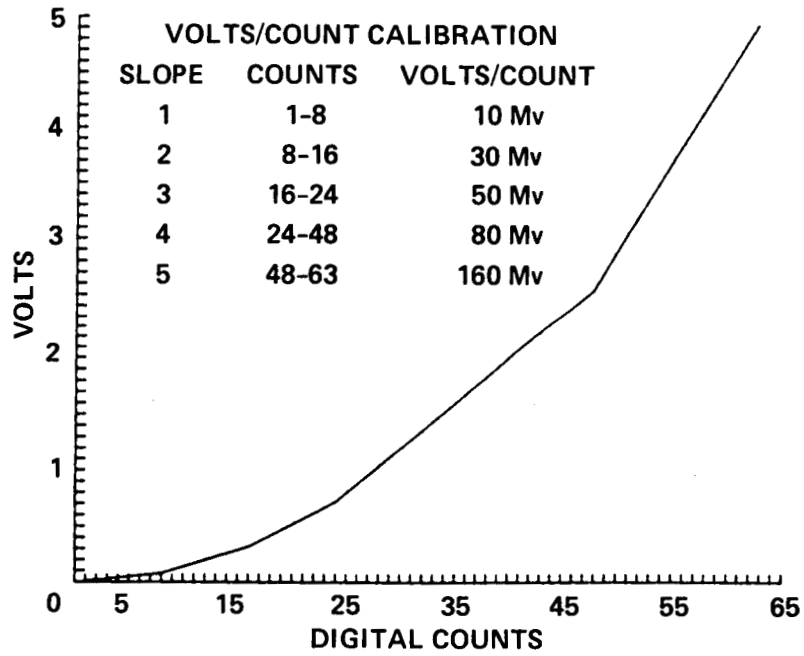


Figure 4.- VISSR volts-count calibration slopes.

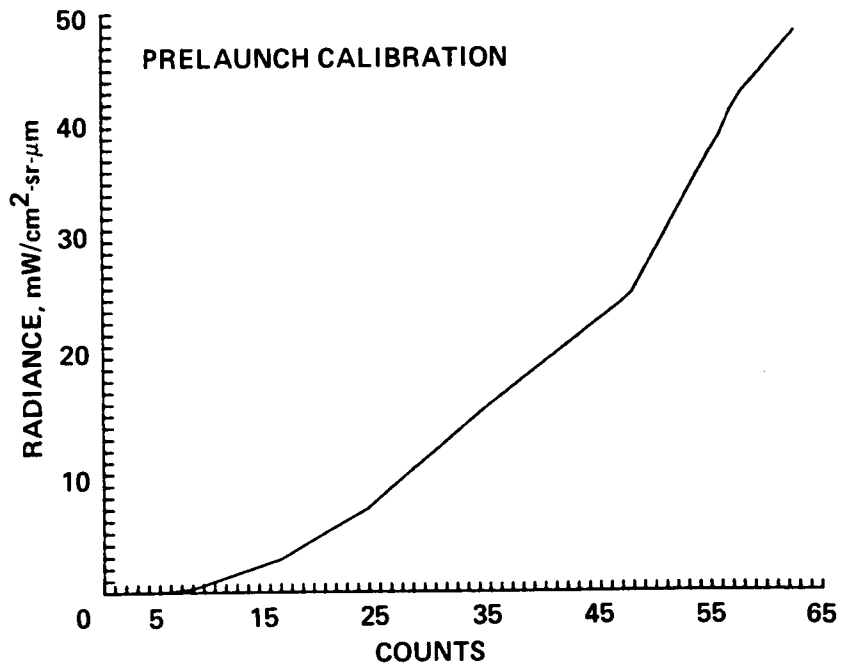


Figure 5.- VISSR prelaunch radiance calibration.

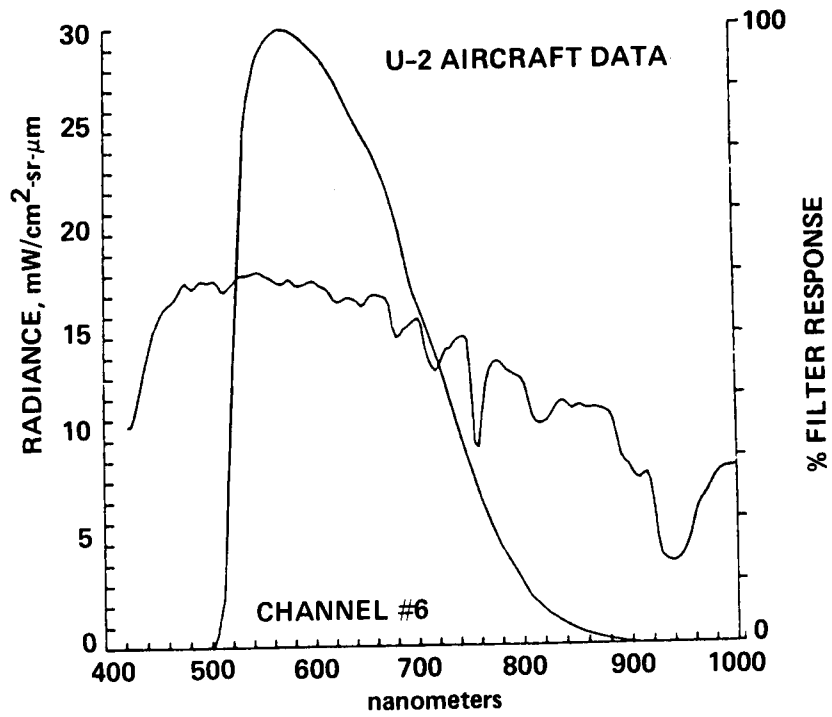


Figure 6.- U-2 aircraft data.

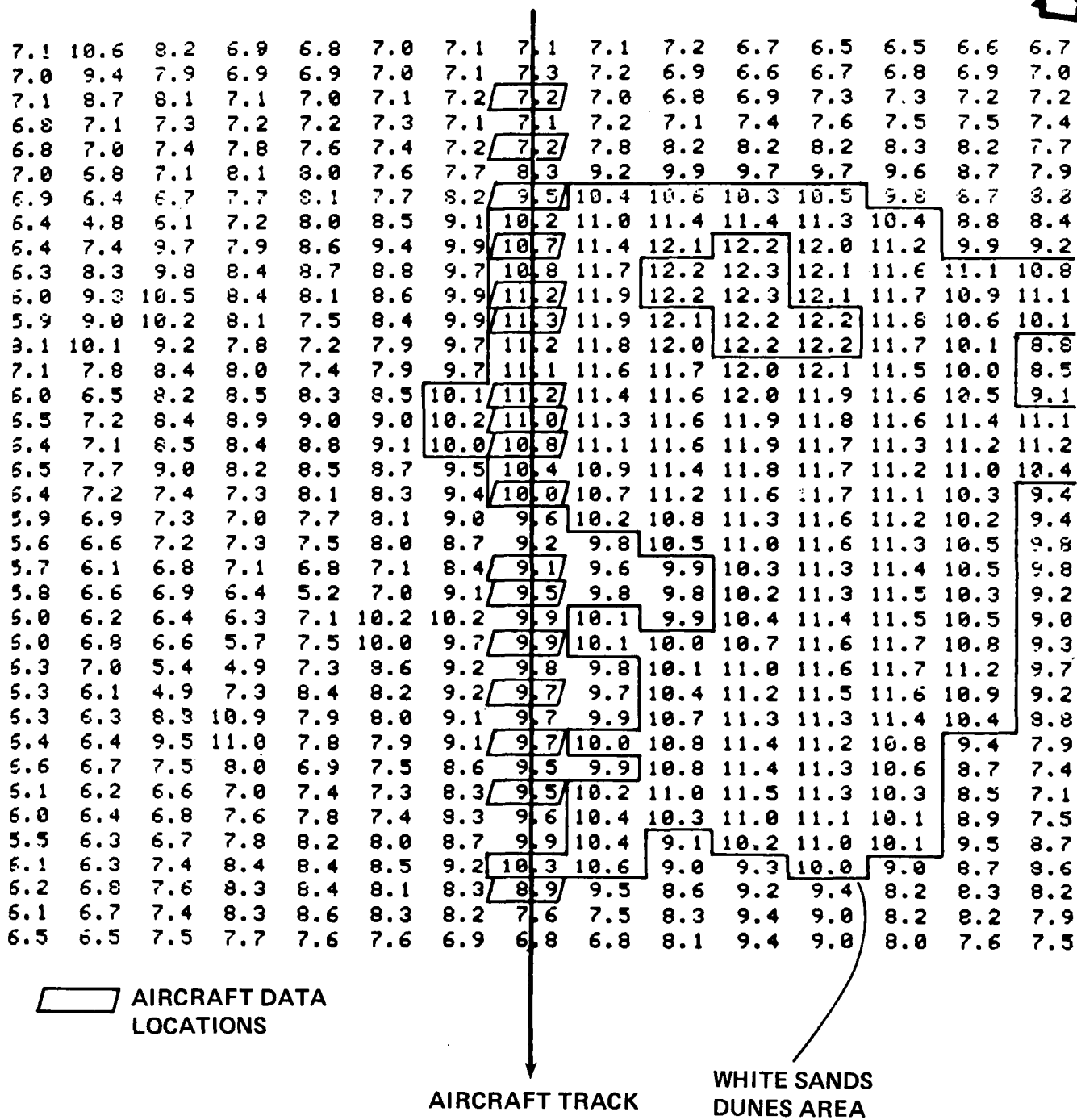


Figure 7.- VISSR radiance data sector.

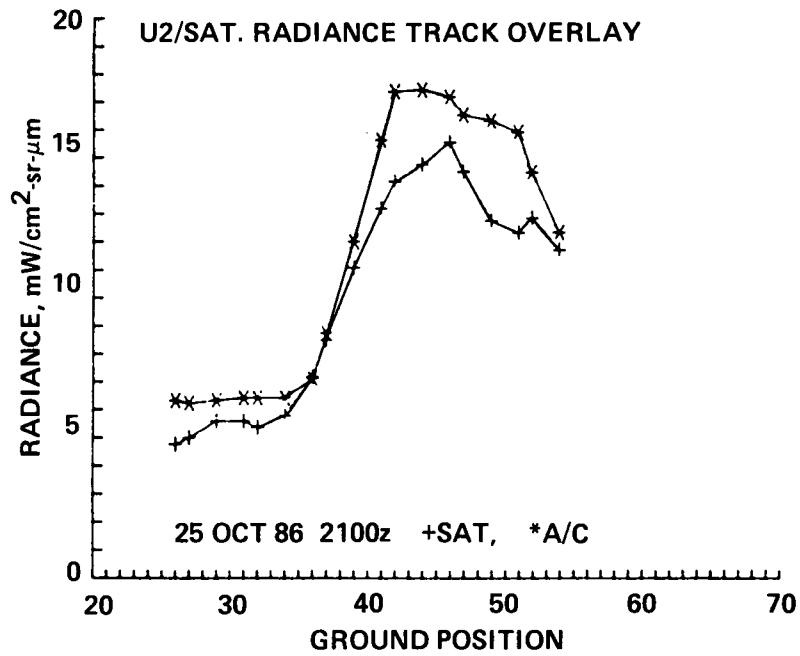


Figure 8.- Brightness contour fit, U-2/satellite.

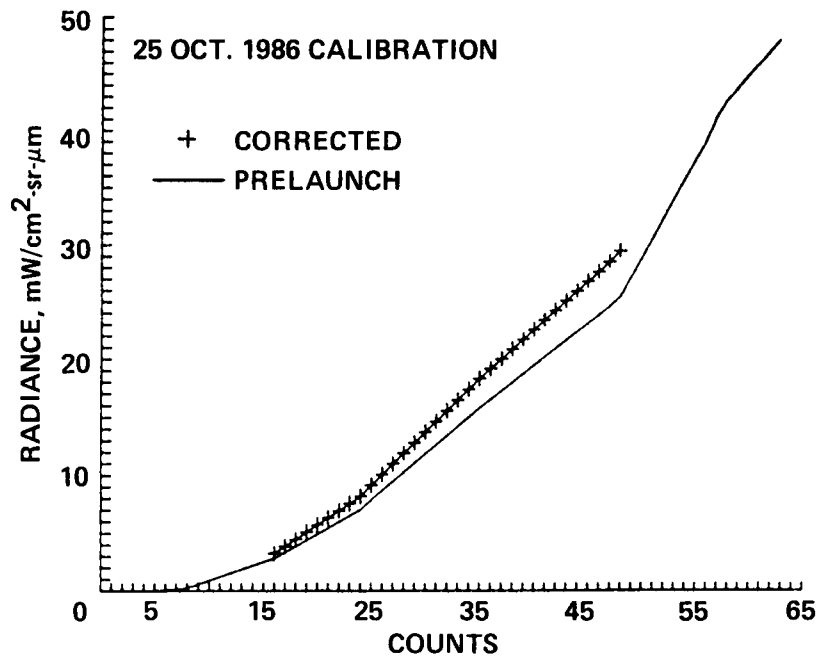


Figure 9.- VISSR radiance calibration, 1986.



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