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SUMMARY

Visible near-infrared sensors mounted on operational satellites now in use do not have on-board full aperture absolute calibration devices. One means of establishing an in-orbit calibration for a satellite sensor is to make simultaneous measurements of a bright, 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 at satellite overpass time for the Landsat-5 Thematic Mapper (TM). A comparison of the coincident aircraft and orbiting satellite data showed the radiometric gain for TM channel 1 had degraded 4.7% by August 28, 1985; the gains for TM channels 2 and 3 were within 1% of prelaunch values.

INTRODUCTION

To make long term studies of global trends feasible, the satellite data user community needs calibrated data products from the visible/near-infrared wavelength channels of the instruments aboard geostationary and polar orbiting satellites. Although the Thematic Mapper (TM) has an on-board calibration system using eight small lamps which are placed in the field of view periodically, it has no on-board extended source calibration system for the visible/near-infrared wavelengths. Assuming a constant target, changes in the observed output of the visible/near-infrared 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 use of 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 in this method, and the aircraft measurement becomes a near-duplicate of the satellite measurement.

In the calibration presented in this paper, the aircraft radiance is corrected for the small amount of atmosphere above the aircraft and then compared to the coincident co-located 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. The White Sands area is a desirable surface calibration target because the probability for clear sky is great. Also, the characteristics of the atmosphere over White Sands have been well documented for a number of years. The reflectance of the surface of the White Sands of 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 and satellite calibration missions over the White Sands area (refs. 1,2,3). A calibration (ref. 4) of the visible channels of the NIMBUS-7 Coastal Zone Color Scanner was also accomplished by NESDIS using the method described above, but flown over ocean water.

SATELLITE INSTRUMENT CALIBRATION

Prelaunch calibration of the visible and (near-infrared) channels of a satellite instrument presents a problem in that 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 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 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 LANDSAT-5 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 typical NESDIS aircraft data-gathering field mission is illustrated in figure 2. Not all of the measurements illustrated in figure 1 were conducted during a specific field mission. In August, 1985, data were gathered from the U-2 over White Sands in parallel with the view vector of the LANDSAT-5 TM. The NASA Ames U-2 aircraft was flown out of Moffett Field, California.

Aircraft Instrument– The NESDIS U-2 instrument measured in visible and near-infrared wavelengths. The instrument was a 1/8-m focal-length, rapid-scanning, Ebert zero dispersion 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 ±0.5%. The nadir footprint (field of view) size of the TM is approximately 0.030 × 0.030 km. 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.

THEMATIC MAPPER

At the vendor facility, channels 1, 2, 3, and 4 (fig. 2) of the TM were calibrated in radiance using a sphere source supplied by NASA GSFC. Radiance in the bandpass of these channels can be compared with aircraft measured radiance. Figure 4 shows the channels 1, 2, 3, and 4 prelaunch calibration in radiance versus count, produced from the vendor data. No significant changes have been observed in the zero count levels of the TM visible of near-infrared channels.

AIRCRAFT DATA—TM CALIBRATION

The U-2 instrument scans the visible/near-infrared wavelength region from 400 to 1050 nanometers with a spectral resolution of 7 nm. A typical ten-second spectral scan of U-2 aircraft instrument data is shown in figure 5. The visible spectrum of White Sands is shown along with the spectral responses of TM channels 1, 2, 3, and 4 from figure 3. Aircraft measured radiance is calculated as a convolution of the aircraft instrument spectrum with the figure 3 TM spectral response functions. When corrected for the effects of the atmosphere remaining above the aircraft, the aircraft measured radiances in all channels are comparable to those calculated from the satellite instrument.

A direct geometric comparison cannot be made between the radiance level of the TM 30 × 30-m pixel and the U-2 instrument field of view of 2.5 × 2.5 km at altitude due to the large difference in size. The satellite data can be made to be comparable to the aircraft data through averaging and sampling. Using only TM forward scans, each consisting of 16 scan lines, a satellite radiance field was generated by averaging a 3 × 3 array of 16 × 16 pixel blocks, with 32-pixel spacing between blocks along the scan. This array represents a 25% sample of an area of 2.86 km square which is comparable to the aircraft field of view. One of the data fields created by this method is shown in figure 6, the White Sands sector of TM channel 2. The White Sands Dunes area is outlined in figure 5 where the satellite data field is specified in radiance units of mW/[cm^2 * Sr. * μm]. This data set is based on the vendor prelaunch calibration. Atmospheric transmission measurements were used to account for the effects of the atmosphere above the aircraft. This small correction was applied to the aircraft measured radiance and is discussed in detail in the section "Correction for the Atmosphere Above the Aircraft." The figure 6 numerical 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 5. This nonuniformity is utilized as a means to co-locate 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. 7) of the aircraft data. Each parallel track of averaged 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 6, only one track of data is found to have a brightness contour similar to the aircraft data. Figure 6 shows the TM channel 2 comparison of the computer selected data sets and is a typical example of the ground co-location of the satellite and aircraft data. The latitude and longitude data from both the aircraft and the satellite data sets is used to produce a preliminary co-location of the data sets but this error is ±1 km, whereas the contour fit error is ±0.5 km.

Figures 8 and 9 show the LANDSAT-5 TM channels 1, 2, 3, and 4 prelaunch calibration radiance versus counts along with the U-2 radiance, corrected to the top of the atmosphere for August, 1985. At this time the LANDSAT-5 satellite had been in orbit for 17 months. The figure 8 channel 4 data show a satellite radiance level based on the prelaunch calibration that is 12.5% higher than the aircraft data. This indicates that there could be an error in the channel 4 prelaunch calibration. Aircraft data are 4.7%

higher than the prelaunch calibration for TM channel 1 (fig. 8). Aircraft data for channels 2 and 3 show a radiance level within 1% of prelaunch (fig. 9). The error of radiance calibration measurement, Table 1, is ±2.56%.

GROUND PARAMETER MEASUREMENTS

Extensive ground parameter measurements were made by Dr. Phillip N. Slater of the University of Arizona, coincident with the Landsat overpass. Ground radiance measurements were recorded over an area of White Sands equal to one TM pixel size. Low altitude radiance measurements were recorded from a helicopter flown at various altitudes. Ground level solar spectra were recorded. The NOAA provided surface soil moisture measurements (ref. 7) and Rawindsonde observations (RAOB) to balloon burst satellite overpass time.

Correction for Atmosphere Above the Aircraft

Empirical measurement 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 this data set the atmospheric transmission was found to be above 0.99 for all 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 550 and 600 nm decreases the atmospheric transmittance less than 2%. The only other atmospheric absorption detected was the narrow oxygen band at 762 nm. The Arvesen data were 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 ±0.2%. The path radiance contributed by the atmosphere above the aircraft to the satellite radiance was ignored as insignificant in relation to 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 in TM channels 1, 2, 3, and 4. Hence, the combined error resulting from the correction 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 zero counts, and the calibration coefficient. The zero radiance level for channel 1 is 1.8 counts, for channel 2, 1.7 counts, for channel 3, 1.9 counts and for channel 4, 2.2 counts.

A summary of calculated radiance calibration coefficients for the LANDSAT-5 TM is as follows.

	Prelaunch	**August 1985**
Channel 1	0.064	0.067
Channel 2	0.128	0.129
Channel 3	0.098	0.099
Channel 4	0.092	0.082

CONCLUSIONS

The work reported in this paper demonstrates that the visible and near-infrared channels of satelllite instruments may be effectively calibrated using high altitude aircraft data. Aircraft data gathered on a regular basis would produce a data set that would monitor the performance of the satellite instrument. This data set would be valuable to the satellite data user community and would provide validation for the atmospheric modelling 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. diameter sphere	±1.5%
III.	Aircraft Spectrometer Wavelength determination Electronic noise	 ±0.2% ±0.1%
IV.	Data Analysis Correction for the atmosphere above the aircraft	±0.5%
	Total radiance uncertainty	±2.56%

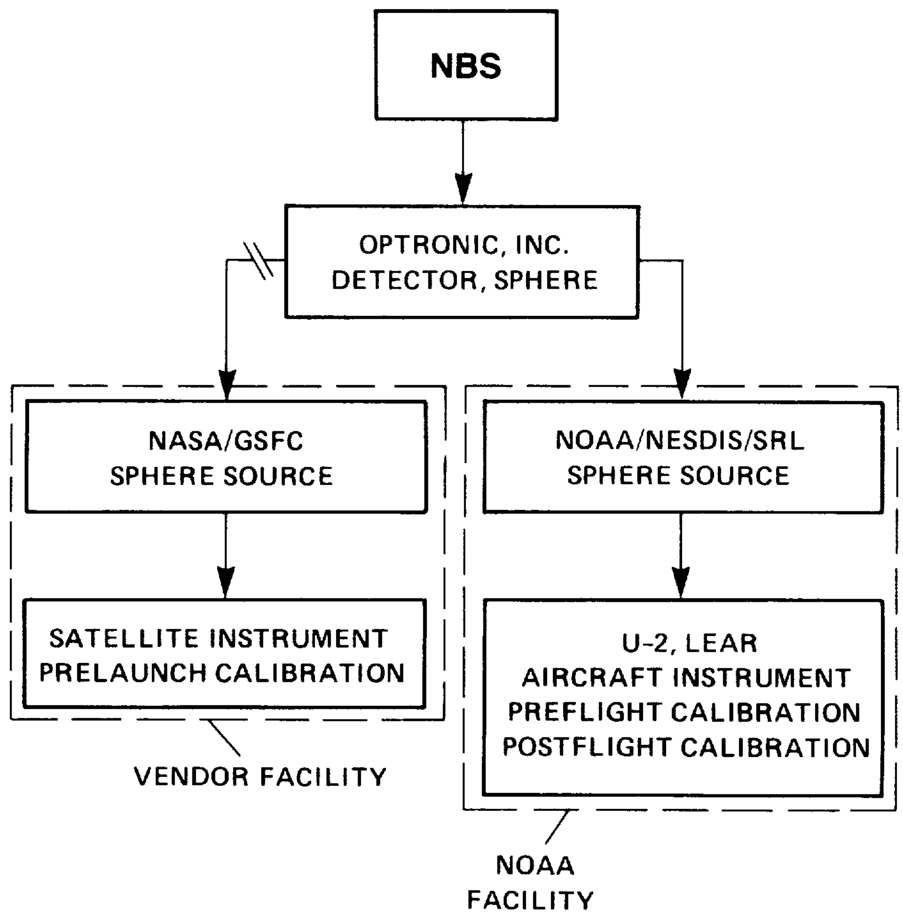
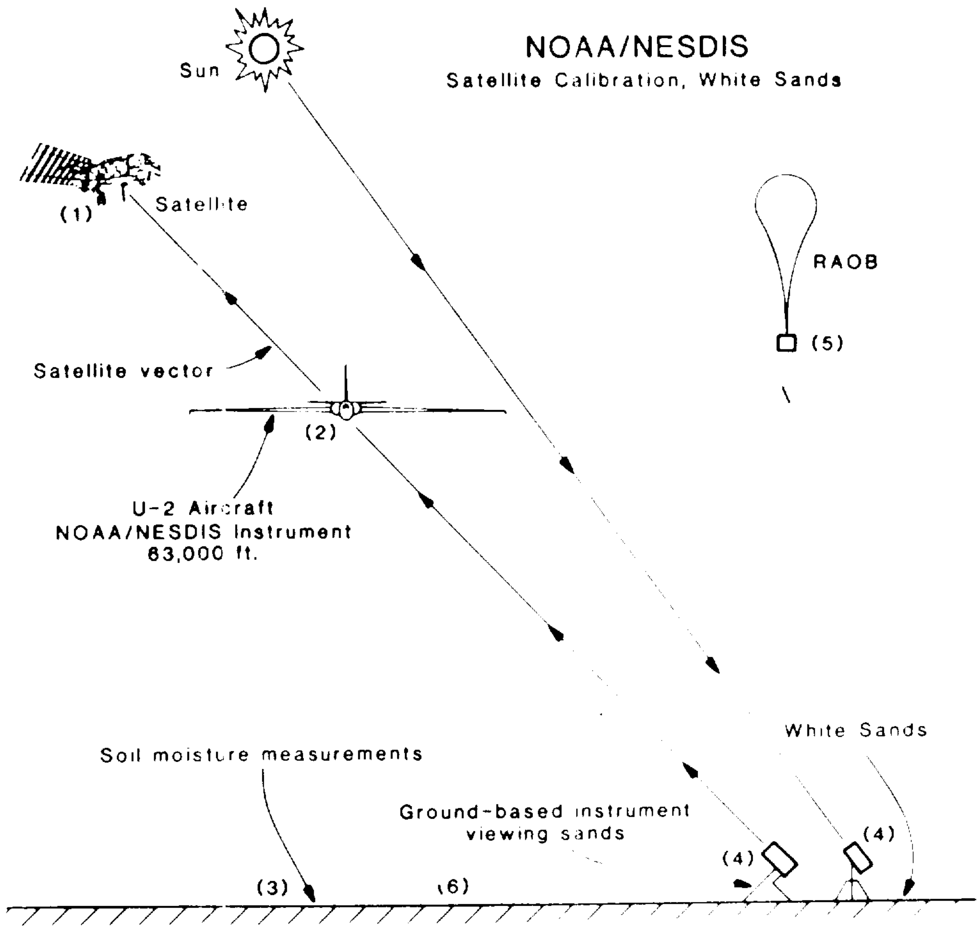


Figure 1.– NBS calibration traceability.



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.

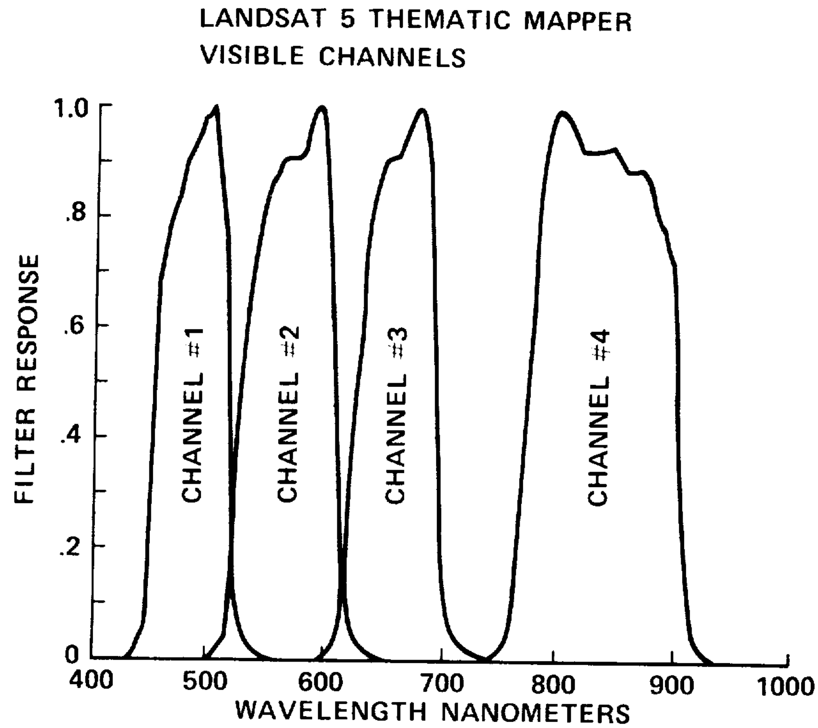


Figure 3.– LANDSAT-5 TM Channels 1, 2, 3, and 4 bandpass.

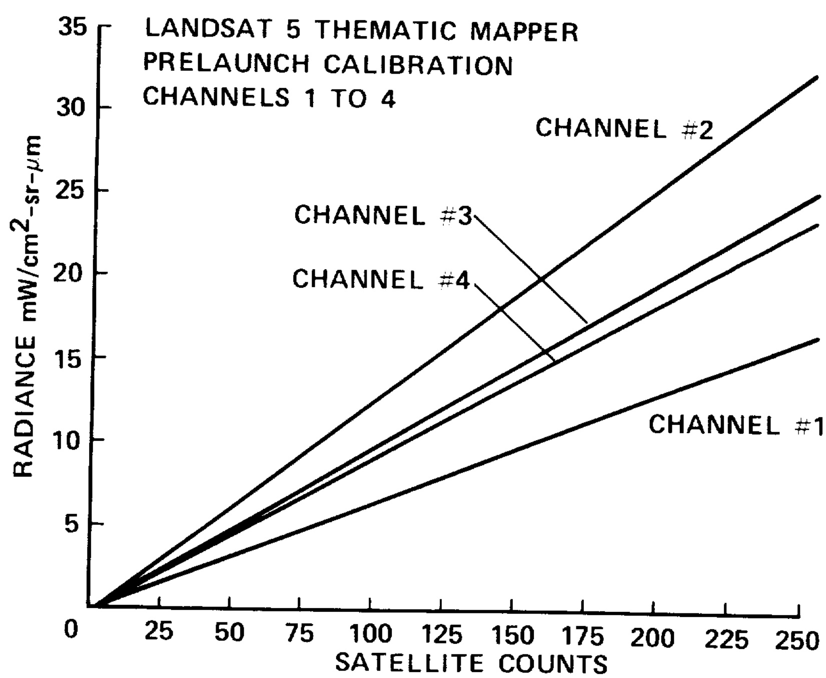


Figure 4.– TM prelaunch calibration.

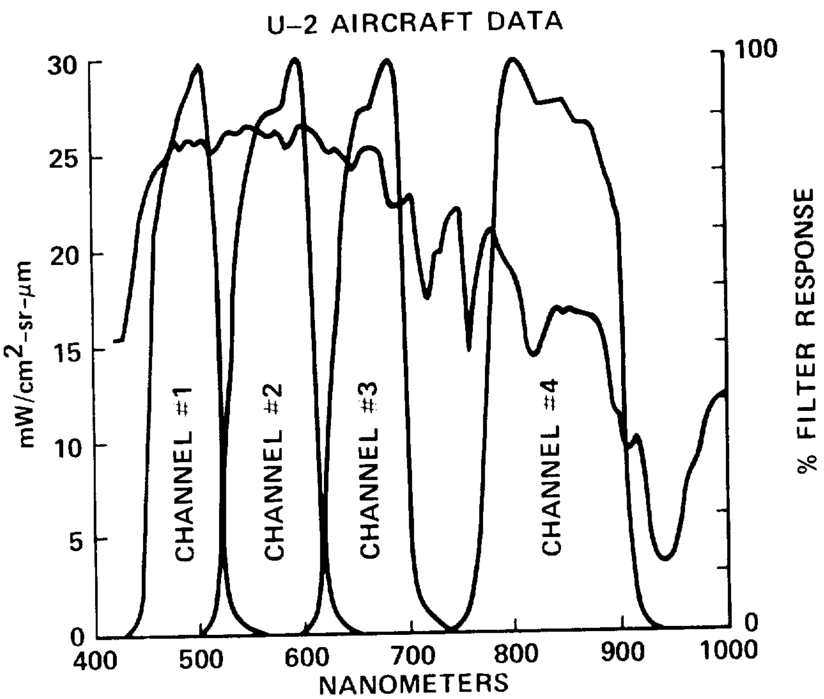


Figure 5.– U-2 aircraft data.

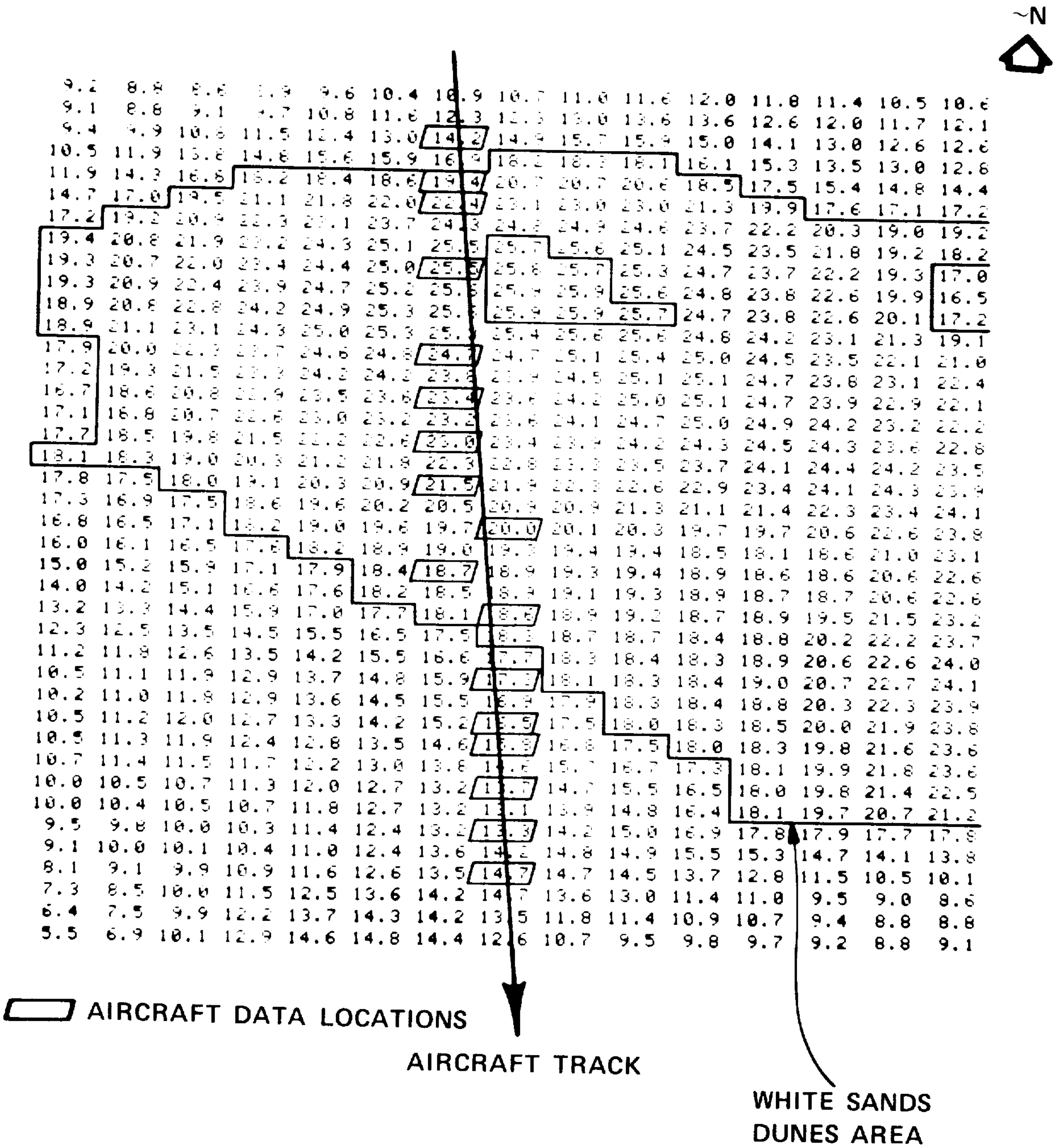


Figure 6.– TM Channel 2 data sector.

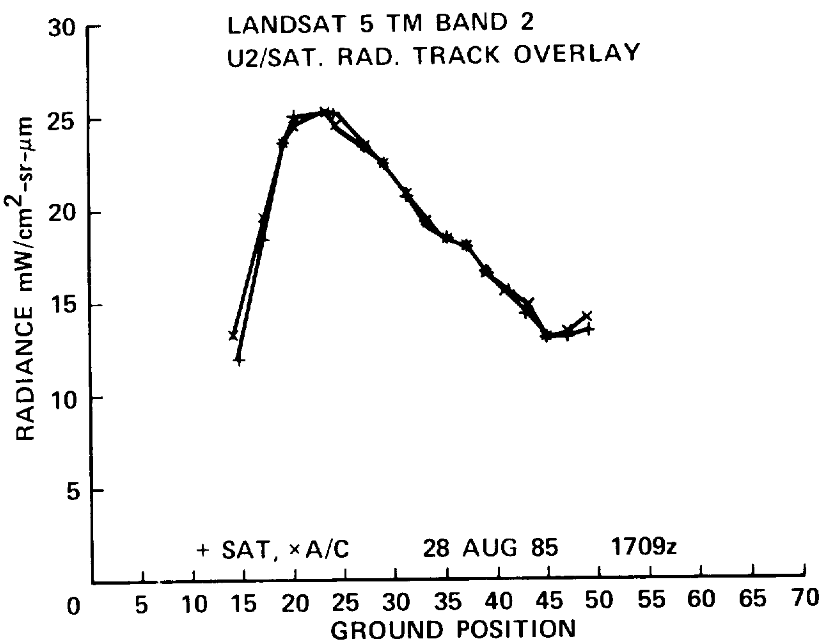


Figure 7.– Brightness contour fit, U-2/satellite.

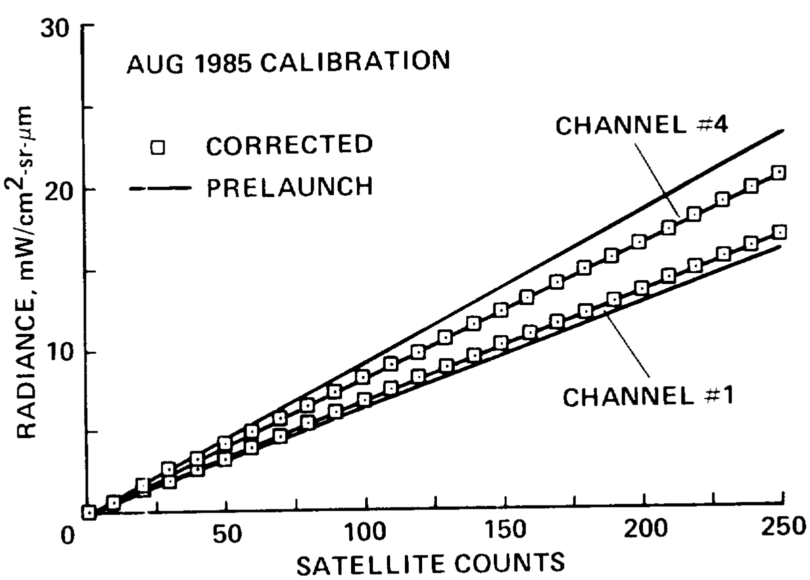


Figure 8.– Channels 1 and 4 TM calibration.

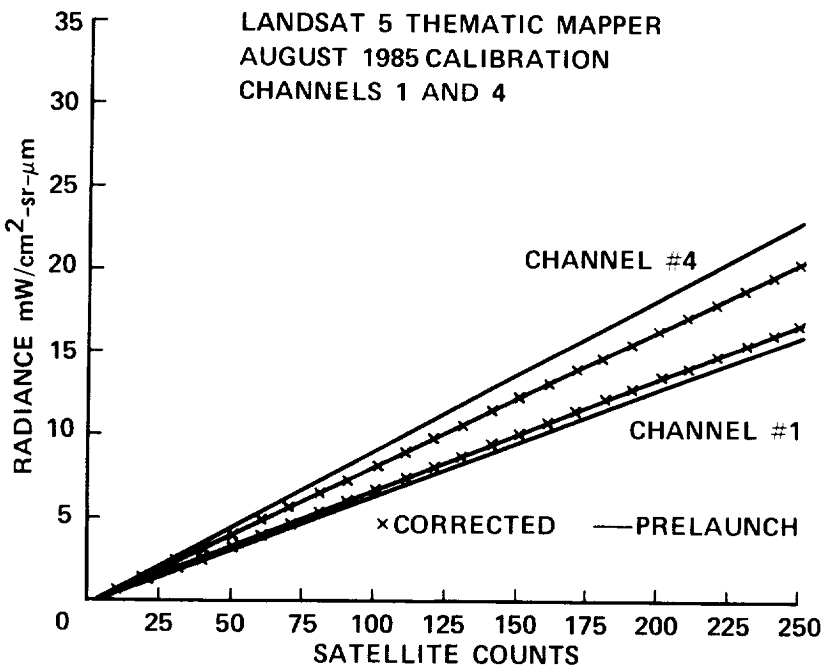


Figure 9.– Channels 2 and 3 TM calibration.

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16. Abstract

Visible near-infrared sensors mounted on operational satellites now in use do not have on-board full aperture absolute calibration devices. One means of establishing an in-orbit calibration for a satellite sensor is to make simultaneous measurements of a bright, 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 at satellite overpass time for the Landsat-5 Thematic Mapper (TM). A comparison of the coincident aircraft and orbiting satellite data showed the radiometric gain for TM channel 1 had degraded 4.7% by August 28, 1985; the gains for TM channels 2 and 3 were within 1% of prelaunch values.

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