GMS Operational Calibration Procedure and Status*

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Abstract

This report briefly summarizes the operational calibration procedure of the Visible and Infrared Spin Scan Radiometr (VISSR) and the present calibraton status.

The infrared calibration procedure utilizes space and the calibration shutter as the reference targets. Judging from the thermal gradient within the sensor scanner unit, infrared data are not well calibrated.

Visible calibration procedure, which utilizes space and the sun as the reference targets, has not been performed operationally up to the present. A "normalization" procedure has been carried out for the purpose of reducing the "stripes" instead of the visible calibration procedure. The pre-prepared conversion table of count values to "Albedo" for the reference channel is fixed at present.

1. Introduction

In recent years, satellite data are used for understanding climatic changes and mechanisms. Hence, quantitatively accurate data are required for those purpose. If we extract physical and meteorological parameters from rediances observed by satellite radiometer, we must understand exactly what the instrument measures, how telemetry is handled and how count values related to physical quantities.

This report briefly summarizes the operational calibration procedures performed by the Meteorological Satellite Center of the Japan Meteorological Agency (JMA) and present calibration status.

Both the GMS and GMS-2 have the Visible and Infrared Spin Scan Radiometers (VISSR) on board. These instruments have two infrared channels and eight visible channels. The VISSR provides measurements of the earth and its atmosphere in the 0.55 μm to 0.75 μm wavelength bands in daylight hours, and measurements of radiant energy emitted from the earth and its atmosphere in the 10.5 μm to 12.5 μm day and night. Two sets of the sensors are available, and each set consists of one infrared and four visible sensors. One set is operational one, and the other backup one. Fig. 1 shows an illustration of the spin-scan geometry and the picture data format of the GMS VISSR. The characteristics of the VISSR are shown in Table 1.

In order to convert a count value of the VISSR data into a physical quantity (albedo, radiance, temperature), a pre-prepared conversion table is used. A new conversion table is generated daily using the procedure described below and compared with the previous table. If the difference between the new and the previous table is statistically significant, the conversion table is updated. The data set used by the calibration proce-

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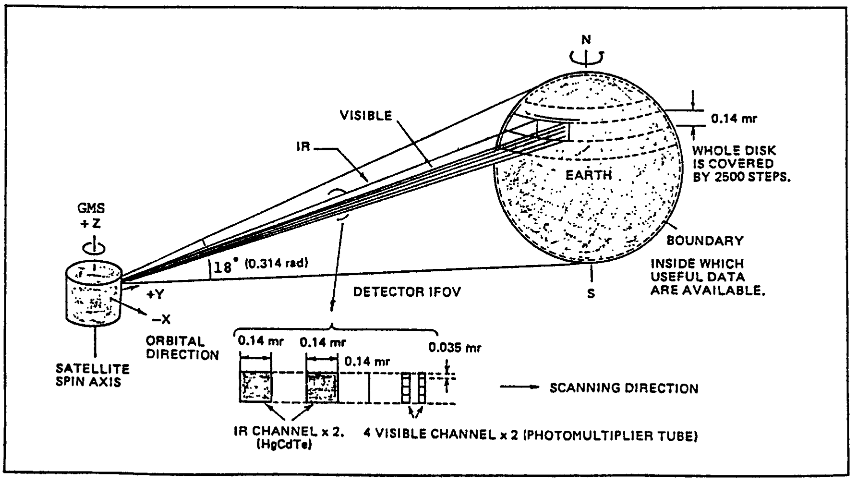

Fig. 1 Schematic diagram of VISSR scanning.

Table 1 Characteristics of VISSR.

Wave length	Vis. 0.5 – 0.75 μm IR 10.5 – 12.5 μm
Resolution at the sub-satellite point	Vis. 1.25 km IR 5.0 km
Instantaneous field of view	Vis. 35 x 31 μ rad. IR 140 x 140 μ rad.
Scan step angle	140 μ rad. (north-south scanning)
Temperature accuracy	0.5°K or less (when observing an object of 300°K) 1.5°K or less (when observing an object of 220°K)
Number of scan lines	Vis. 2500 x 4 IR 2500
Frame time	27.5 minutes (including 2.5 minutes for mirror retrace)
Power consumption	25 W
Weight	67 kg (including 6 kg of electronics)
Aperture	40.6 cm in diameter
Focal length	291.3 cm
Gray level	Vis. 64 (6 bits) IR 256 (8 bits)

dures is the previous day's VISSR data; eight infrared observations, four visible observations and the correlated telemetry data.

The VISSR has two inflight calibration procedures (i.e. the conversion of count values to sensor output voltages, and the conversion of the sensor output voltages to a physical quantity) for both the visible and infrared channels (see Fig. 2). The former uses a 0-volt to 5-volt staircase response inserted in both the visible and infrared channel signal paths. The latter utilizes two targets for both the visible and infrared sensors. The visible channel targets are space and the sun. The space view provides a zero percent albedo response. The sun, as viewed through an energy reducing prism, provides an equivalent earth albedo response of approximately fifty percent. The count value from the solar observation can be obtained only once a day. The infrared channel targets are space and the calibration shutter. The space view provides a near zero response, while the shutter view provides the response to a target with a temperature of near 300°K. The operational procedure for the visible channels described above has not yet been carried out, because of the occurrence of "stripes" on the pictures which arises from differences between detectors sensitivity. At the present time, a "normalization" procedure is performed for the purpose of reducing the "stripes" instead of the above calibration procedure. In this procedure, a refernce channel, to which the other channels are normalized, is chosen. The look-up conversion table of the reference channel is fixed.

In Section 2, a staircase calibration procedure is described. In Section 3 and 4, a

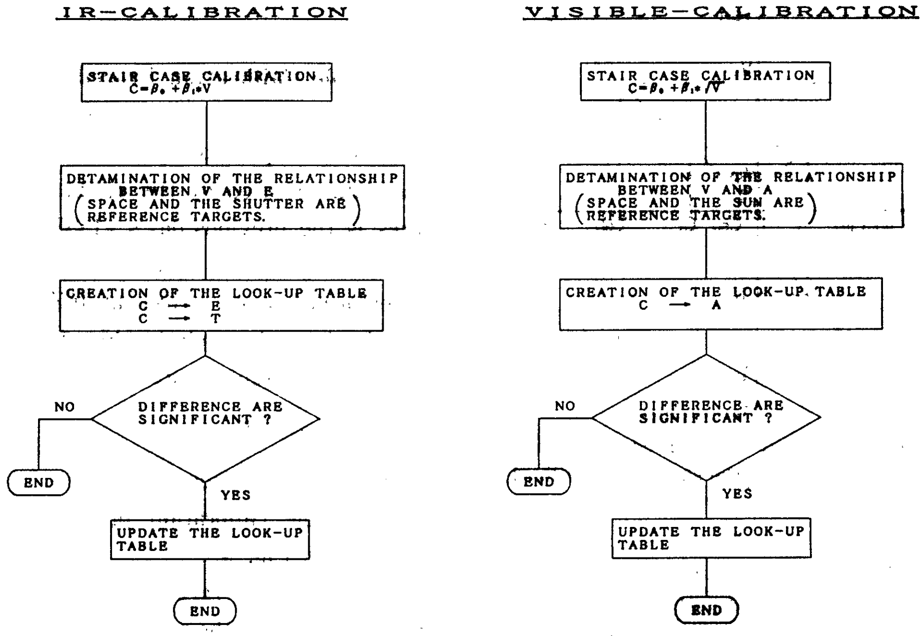

Fig. 2 Simplified flow chart of calibration procedure.

generation of the look-up tables which convert count values to a physical quantity for the infrared and visible calibration are presented, respectively. In Section 5, a normalization procedure of the visible calibration is stated.

2. Staircase Calibration Procedure

The staircase calibration is a procedure which determines the relationship between count values and sensor output voltages. The count values are related to the voltages by the following equations,

$$\text{Visible: } C=\beta_0+\beta_1\cdot\sqrt{V} \quad \text{(6-bit scale)} \qquad (1)$$

and

$$\text{Infrared: } C=\beta_0+\beta_1\cdot V \quad \text{(8-bit scale)}, \qquad (2)$$

where C and V are a count value and the voltage respectively. The coefficients β_0 and β_1 are empirically determined by the least squares method once a day. If the new determined β_0 or β_1 is significantly different from the previous one (F-test, a 95% confidence limit), the β_0 and β_1 are updated.

3. Infrared Calibration Procedure

In this section, a description is given of how infrared radiances are related to sensor output voltages, and how the count values are converted to radiances and equivalent black body temperatures.

It is assumed that the relation between a sensor output voltage (V) and the radiance (E) is linear:

$$V=\alpha_0\cdot E+V_0 \qquad (3)$$

where V and E are a voltage and the radiance respectively. The α_0 and V_0 are the coefficients to be determined. The data set used by the calibration procedures is the previous day's VISSR data; eight infrared observations and the correlated telemetry data. The infrared calibration processings

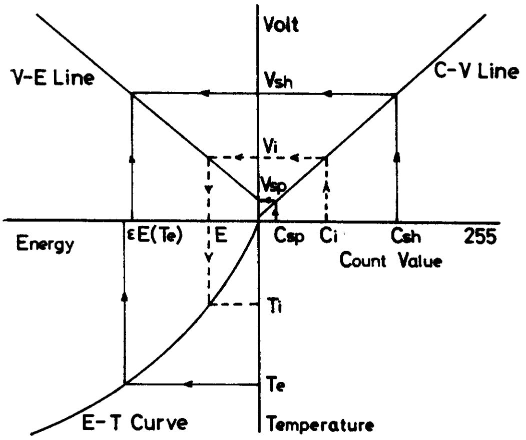

Fig. 3 Schematic view of infrared calibration procedure. Space and the shutter are utilized as the refrence.

are performed as follows (see Fig. 3):

(1) Space voltage (Vsp) and shutter voltage (Vsh) are determined by substituting space count value (Csp) and shutter count value (Csh) into the equation (2) (seen Section 2) for the eight infrared observations;

(2) Coefficients α_0, V_0 are calculated using the following equations,

$$V_0=Vsp \tag{4}$$

and

$$\alpha_0=(Vsh-Vsp)/Esh\,, \tag{5}$$

where Esh is an effective shutter radiance, while space radiance is assumed to be zero (see Appendix (i));

(3) The mean ($\bar{\alpha}_0$, $\bar{V}_0$) and variance of the data set (α_0, V_0) are calculated, and then compared with the previous ones. If $\bar{\alpha}_0$ or $\bar{V}_0$ is significantly different from previous one (i. e. t-test, a 95% confidence limit), the conversion tables is updated. The conversion table of count values to radiances can be obtained from the equations (2), (3) and the conversion table of radiances to equivalent blackbody temperatures (see Appendix (ii)). When the β_0 or β_1 is updated, the conversion table is also renewed.

4. Visible Calibration Procedure

In this procedure, an albedo is related to the sensor output voltage for each channel. The data set used by the calibration procedures is the previous day's VISSR data; four visible observations. The solar observation is performed once a day at 16Z. It is assumed that the relationship between an albedo and the sensor output voltage is linear:

$$V=\alpha_0\cdot A+V_0\,, \tag{6}$$

where A is an albedo.

The visible calibration procedure are as follows (see Fig. 4):

(1) Mean and variance of space count values (Csp) and the sun count values (Csn) are calculated from the visible observations. If a difference between the new and the previous value in Csp or Csn is statistically significant (i. e. t-test, a 95% confidence limit), the Csp or Csn is updated.

(2) Space voltage (Vsp) and the sun voltage (Vsn) are calculated by substituting the Csp and Csn into equation (1) (see Section 2).

(3) Coefficients α_0, V_0 are determined by the following equations,

$$V_0=Vsp \tag{7}$$

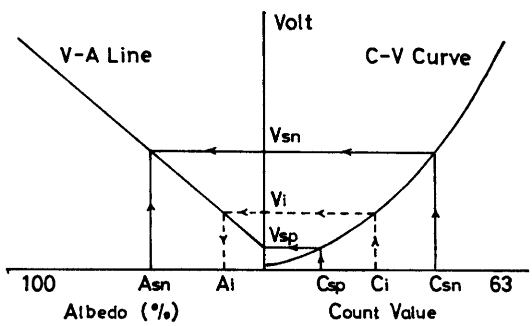

Fig. 4 Schematic view of visible calibration procedure. Space and the sun are utilized as the refrence targets.

and

$$\alpha_0=(Vsn-Vsp)/Asn\,, \tag{8}$$

where Asn is the sun albedo, while space albedo is assumed to be zero.

(4) If the new Csp or Csn is adapted as described in the processing (1), the conversion table is updated using the equations (1) and (6). When the β_0 or β_1 is updated (see Section 2), the conversion table is also renewed.

5. Normalization of Visible Channels

In this section, the normalization procedures used during the processing of visible channel data is described. A reference channel is chosen and count values of the other channels are fitted to count values of the reference channel by the least squares method. The conversion table of count values to albedoes for the reference channel is fixed.

(1) The areas where count values are uniform and smooth are selected as samples. The number of data samples is restricted to less than ten for each 0-to 63-level.

(2) The count values of the samples are substituted into the previous regression function, and the sample residuals are calculated.

(3) If the root mean square (RMS) of the sample residuals is greater than the limit value, the regression function is revised and the conversion table of count value to albedo is updated. The limit value of the RMS is 0.7 for the GMS and 0.8 for the GMS-2.

This "normalization" procedure is adopted instead of the visible calibration described in Section 4. The operational normalization procedure is performed every five days.

Table 2 Parameters for visible normalization procedure. The GMS visible channel #6 was not used for the failure of the detector.

		GMS	GMS-2
OPERATION PERIOD		78. 4. 1.00Z ~ 81.12.21.06Z 84. 1.21.09Z ~ 84. 6.28.12Z	81.12.21.09Z ~ 84. 1.21.00Z 84. 6.28.18Z ~ 84. 9.27.00Z
SENSOR		REDUNDANT	PRIMARY
REFERENCE CHANNEL		CHANNEL #7	CHANNEL #1
$C=\beta_0+\beta_1 \cdot \sqrt{V}$	β_0	−0.23764	−0.309
	β_1	27.728	28.375
SUN COUNT VALUE		33	48
SPACE COUNT VALUE		1	1
SUN ALBEDO (Asn)		30 %	42.5 %

6. Present Calibration Status

The VISSR has two infrared channels and eight visible channels. A set of one infrared and four visible channels is used operationally, the other set serves as a backup one. For visible observations, channels #1-#4 are primary and channels #5-#8 are backup. The channels being used are shown in Table 2. For infrared observations, channel #1 is the primary and channel #2 is the backup. The backup channel had been used in the GMS system and the primary channel has been used in the GMS-2 system.

6.1. Infrared

The infrared calibration is highly dependent on the effective shutter temperature (Te). The effective shutter temperature is given by the equation (see Appendix (i)),

$$Te=Ts+K1\cdot(Ts-Ta)+K2\cdot(Ts-T1)$$

The coefficients $K1$, $K2$ are dependent on the emissivities of the primary and secondary scan mirrors and the mirror obscuration. Their values ($K1=0.325$ and $K2=0.175$) presented from the ground based calibration have been used in both the GMS and GMS-2. We have not been provided with detailed information on how the coefficients $K1$, $K2$ were determined.

After the launch of the GMS-2, it was found that the differences between ground

Table 3 Effective shutter temperature. Values in the parentheses are 95% confidence limits. (after Uchiyama et al., 1984)

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Effective Shutter Temperature ( Te )

(1)  Te = C0 + C1·Tsh1 + C2·Tsh2 + C3·T1 + C4·T2 + C5·T3
         C0 =  3.0643  ( ±2.5365 )
         C1 =  0.2865  ( ±2.7996 )
         C2 = -1.2735  ( ±2.6104 )
         C3 = -0.7035  ( ±0.5781 )
         C4 =  2.0827  ( ±2.5199 )
         C5 =  0.3870  ( ±0.6372 )

(2)  Te = C0 + C1·(Tsh1 + Tsh2)/2 + C2·(T1 + T3)/2 + C3·T2
         C0 =  1.0683  ( ±1.3094 )
         C1 = -0.7749  ( ±2.6990 )
         C2 = -0.3664  ( ±0.1604 )
         C3 =  2.1020  ( ±2.5528 )

(3)  Te = Tsh + C0 + C1·(Tsh - Ta) + C2·(Tsh - T1)
         Tsh = (Tsh1 + Tsh2)/2
         Ta  = (T1 + T2 + T3)/3
         C0 =  1.3603  ( ±0.3151 )
         C1 =  0.9417  ( ±0.6761 )
         C2 = -0.1032  ( ±0.4259 )

(4)  Te = Tsh + K1·(Tsh - Ta) + C0 + C1·(Tsh - T1)
         K1 =  0.325
         C0 =  1.2102  ( ±0.2734 )
         C1 =  0.2816  ( ±0.0399 )
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truth sea surface temperature (SST) data (conventional ship SST) and the satellite derived SST (inferred from the satellite infrared radiances) varied seasonally. From this fact, we infer that the values of the coefficients $K1$, $K2$ are inadequate. We believe that this seasonal variation is caused by the thermal gradient within the sensor scanner unit. Then, we determined the values of the coefficients on the basis of ground-truth SST and theoretically calculated infrared radiances; absorption and emission by water vapour are only considered in the theoretical calculation. The coefficients are shown in Table 3. However, since we could not evaluate the accuracy of the theoretical calculation and the conventional ship SST, we did not use our coefficients.

During the eclipse periods, the diurnal temperature variation within the sensor-scanner unit reaches about 4°K. Therefore, it is not good for these periods to use the count to energy and count to temperature conversion table made from previous day's data. It is considered to make the infrared calibartion using real time image data and associated telemetry data.

6.2. Visible

The reflected radiances which are observed by satellite radiometers are often called "Albedo". The "Albedo" was used in the documentation of pre-launch test, which was provided by the NASDA (National Space Development Agency of Japan). We have not yet obtained any information on the pre-launch test except for the conversion table of "Albedo" to output voltage. It is described in the document that each visible channel was calibrated for each of the 9 "VISSR calibrator albedo" levels. The "VISSR calibrator" was a special equipment for the pre-launch test. We have not been provided any detailed information about this instrument. Therefore, we cannot but interpret the "Albedo" to be a radiance divided by the instrument's spectral solar constant.

During the GMS post-lunch test period, we investigated the quality of the visible data obtained using the visible calibration method described in Section 4. As the result, we have found that the solar observations from the GMS are not stable as shown in Fig. 5 and we can not measure them during the eclipse periods. Furthermore, we have found that "stripes" occurred due to the differences of sensitivity between detectors. At that time, we were interested in the relative distribution of reflected radiances and not the derivation of physical and meteorological parameters from the visible data. Therefore, it was decided to eliminate the "stripes" from the visible pictures rather than perform radiometric calibration.

Table 2 gives the coefficients used to produce a conversion table for the reference channel. The calibration coefficients were determined on the basis of data obtained during the GMS post-launch test period. The

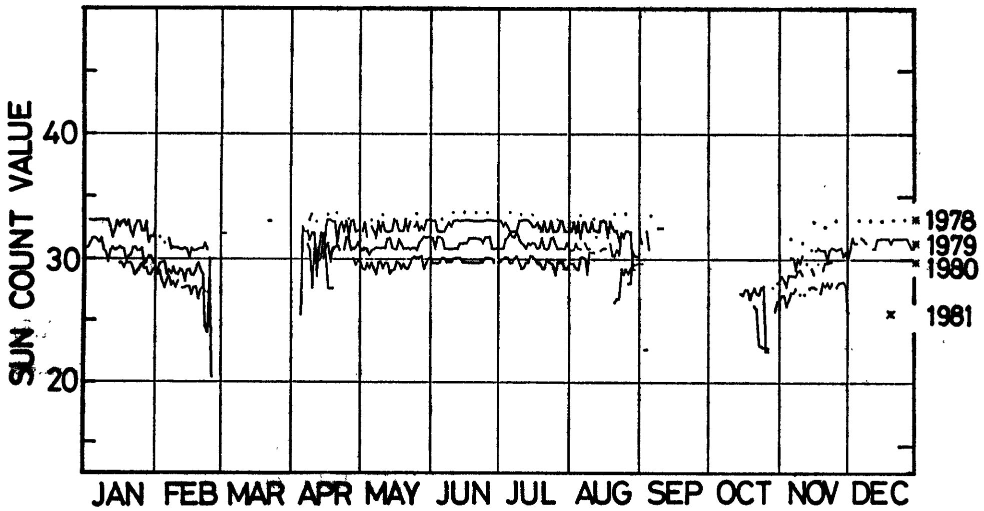

Fig. 5 Solar observations. The sun count values are unstable and decreasing gradually. Solar obervations cannot be performed during the eclipse periods.

Asn=30% shown in Table 2 was set using the pre-launch calibration table (sensor output voltage/albedo).

The GMS-2 data processing system also uses this normalization procedure. The sun albedo Asn for the GMS-2, which was measured during the post-launch test period using the pre-launch calibration table (sensor output voltage/albedo), was about 57%. Using the Asn=50%, the GMS-2 images were found to be brighter than the GMS ones. The Asn=42.5% given in Table 2 was being used in order to fit the GMS-2 brightness to the GMS one. Furthermore, the GMS-2 gain is greater than the GMS, and so the count values are saturated.

Appendix (i)

Effective Shutter Temperature

The infrared on-board calibration utilizes two reference targets, which are space and the blackbody shutter. The shutter is inserted into the infrared channel optical path between the scanners and the detector. The shutter temperature is corrected taking account of the radiance contribution from the scanners. The effective shutter temperature (Te) is expressed as,

$$Te=Ts+K1\cdot(Ts-Ta)+K2\cdot(Ts-T1), \quad (A.1)$$

$$Ts=(Tsh1+Tsh2)/2 \quad (A.2)$$

and

$$Ta=(T1+T2+T3)/3, \quad (A.3)$$

where

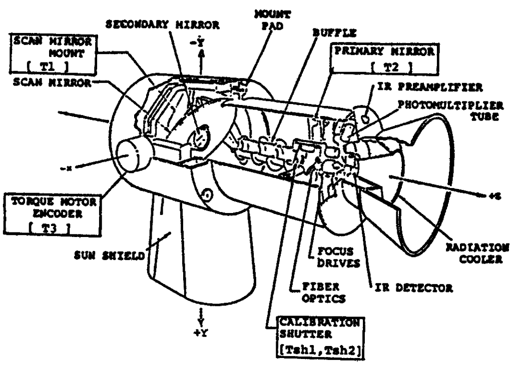

Fig. A.1 VISSR temperature sensor location.
T1: scanner temperature 1
T2: scanner temperature 2
T3: scanner temperature 3
Tsh1, Tsh2: shutter temperature 1, 2.

*Tsh*1, *Tsh*2: shutter temperature, and

*T*1, *T*2, *T*3: scanner temperature.

The coefficients *K*1, *K*2 were determined by the pre-launch calibration. The $K1=0.325$, $K2=0.175$ are used for both the GMS and GMS-2. The VISSR temperature sensors location is shown in Fig. A.1. The effective shutter radiance, *Esh*, is given by the following equation,

$$Esh=\frac{\varepsilon\int_{\lambda_1}^{\lambda_2}\phi(\lambda)B(\lambda, Te)d\lambda}{\int_{\lambda_1}^{\lambda_2}\phi(\lambda)d\lambda} \qquad \text{(A.4)}$$

where $B(\lambda, T)$ is the Planck function, λ is wavelength ($\lambda_1=10.5\,\mu m$, $\lambda_2=12.5\,\mu m$), $\phi(\lambda)$ is a spectral response function and ε, which is equal to 0.995 for both the GMS and GMS-2, is an emissivity of the shutter.

Appendix (ii)

Relation between radiances and the equivalent blackbody temperatures

Radiances $E(T)$ are calculated by the following equation,

$$E(T)=\frac{\int_{\lambda_2}^{\lambda_2}\phi(\lambda)B(\lambda, T)d\lambda}{\int_{\lambda_1}^{\lambda_2}\phi(\lambda)d\lambda} \qquad \text{(A.5)}$$

It is difficult to solve equation (A.5) for temperature (T). Therefore, values of radiance are calculated for temperatures using the equation (A.5) with increments of 0.25°K between 170°K and 330°K, and then a temperature/radiance conversion table is used for converting radiance (E) into temperature by a linear interpolation of the values given in the table.

GMS キャブリレーション処理と現状について

内 山 明 博

気象衛星センターシステム管理課

この報告は，1984年3月6日から8日に東京で開催された Working Group on Data Management Plan Meeting で提出した VISSR のキャリブレーション処理と現状についての報告を転載したものである。

赤外のキャリブレーション処理は，宇宙空間と黒体シャッターからの放射を基準として行っている。しかし，放射計の内部に温度勾配があるため，赤外データはかならずしも十分に較正されているとは言えない。

可視のキャリブレーション処理として，基準光源を使う処理は行なっていない。カウント値 (64階調) を「Albedo」へ変換するテーブルは，ミッション・チェックのデータを参考にして作成し現在まで固定されたままである。可視データについては，画像がすじ状になるのを防ぐためノーマライズ処理を行なっているだけである。