Effects of Sensor Degradation and Solar-Sensor Geometry on Land Cover Monitoring Using NOAA/AVHRR Data

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Abstract: The authors studied the effects of the degradation of NOAA/AVHRR sensor sensitivity and the geometry concerning to the zenith and azimuth angles of the sun and a sensor on the monitoring of land cover conditions using multi-temporal AVHRR data. The effect of sensor degradation on calibration of AVHRR visible and near-infrared channels was tested using the data taken in a desert area where the surface albedo was considered to be stable. The effect of solar-sensor geometry was tested using the three temporal data which were observed within a week and in different geometrical conditions and regression analysis was performed to study the effect of geometrical parameters on the correlation of surface albedos and NVI among the three different data.

1.Introduction

As optical sensor data like NOAA/AVHRR contain data variations due to sensor degradation and geometric conditions of ground observation, it is quite important to consider these variations for the creation of wide-range mosaicked images and the monitoring of the ground surface by multi-temporal data.

Two kind of approaches can be considered for the correction of the variations. One is the statistical approach in which the brightnesses of the images are adjusted by a statistical method. But the statistical adjustment causes the loss of the original radiance information. The other approach is to convert the brightnesses of the images to the physical amount like radiance or reflectance. The first step of the latter approach is to establish the accurate calibration method to acquire accurate radiance or reflectance at the sensor observation. The second step is to correct the variations caused by the geometric observation condition based on the model for the atmospheric effect on various geometric conditions.

In this study, first, the radiometric correction of AVHRR visible and near IR data which considers the sensor degradation and solar-zenith angle was tested as the calibration procedure and the effect of this correction was evaluated using the data taken in a desert area where the surface albedo was considered to be stable. Next, the effects of the geometric conditions related to solar zenith and sensor zenith angles were investigated using the three temporal data which were observed within a week and in different geometrical conditions. The latter investigation is expected to make clear the actual variation due to the difference of the geometry and to offer the evidence for the necessity of the appropriate atmospheric correction for the monitoring by multi-temporal satellite images.

2. Effect of Sensor Degradation on AVHRR Radiance

In order to evaluate the effect of the sensor degradation of AVHRR, two AVHRR LAC images observed on 27/Jan.,1986 (NOAA-9) and 30/Jan.,1993 (NOAA-11) were used for the analysis. For each image, total 192 pixel samples were selected within Thar Desert of India under the geometrical conditions in which the solar zenith angle was restricted from 55° to 65° and the sensor scan angle from 0° to 20°. This restriction was applied to confirm the stability of the reflectance of the desert areas.

2.1 Calibration and correction of AVHRR data

(a) Preflight calibration

The calibration for AVHRR visible (CH.1) and near IR (CH.2) data generally uses the coefficient calculated from the preflight test data. In this calibration, the observed radiance in units of $\mu W/cm^2/nm/sr$ is obtained as follows;

$$R_{pre} = \alpha (C-C_0) \qquad (1)$$

where R_{pre} is the observed radiance, α is the preflight radiometric coefficient as follows;

NOAA-9 : CH.1;0.055 , CH.2;0.036 NOAA-11: CH.1;0.047, CH.2;0.028

C is the AVHRR output digital count level, and C_0 is the count level measured when the instrument is observing deep space.

(b) Calibration considering the sensor degradation

As AVHRR visible and near IR data are affected by the sensor degradation at a launching time or during in orbit (Kaufman and Holben (1992)), the calibration considering the sensor degradation is necessary to acquire an accurate radiance at the sensor observation. So, the coefficient by Kaufman and Holben (1992) was applied as the calibration coefficient as follows;

$$R_{deg} = (\alpha / \gamma)(C-C_0) \qquad (2)$$

where R_{deg} is the observed radiance considering the sensor degradation , α / γ is the radiometric coefficient for the test data considering the sensor degradation as follows;

NOAA-9: CH.1 ;0.06320, CH.2;0.04397 NOAA-11: CH.1;0.05927, CH.2;0.04086

(c) Solar zenith angle correction

The radiance values of AVHRR CH.1 and CH.2 change according to the variation of the solar zenith angle by the reason that the reflected radiance from the target pixel is affected by the incident energy of solar illumination. Therefore the observed radiance was normalized by the cosine of solar zenith angle to correct the change of incident solar radiance as follows;

$$R_{sol} = R/\cos\theta_0 \qquad (3)$$

where R_{sol} is the observed radiance considering the solar zenith angle, R is the radiance calculated by Eq. (1) or (2), and θ_0 is the solar zenith angle.

2.2 Result of calibration and correction

Fig.1(a) and 1(b) shows the radiance distribution of AVHRR data (27/Jan. 1986 and 30/Jan. 1993) corrected with preflight calibration coefficients for visible (CH.1) and near IR (CH.2) respectively. Fig. 2(a) and 2(b) shows the radiance after the calibration considering the sensor degradation. These results indicate that the difference of the mean radiance between the two data in Fig.2 is smaller than that in Fig.1. This fact suggests that the calibration considering the sensor degradation is useful for the comparison of multi-year AVHRR data taken by different satellites.

Fig.3(a) and 3(b) show the radiance distribution of AVHRR data (27 Jan. 1986 and 30 Jan. 1993) after the calibration considering the sensor degradation and after the solar zenith angle correction. In these figures, the difference of mean radiance between the two data becomes smaller after the solar zenith angle correction. In addition, the mean radiance values of the two data are nearly same in the range where the sensor scan angle is small. This fact suggests that the consideration of the sensor degradation can result in more appropriate correction by the combination of the solar zenith angle correction.

2.3 Discussion

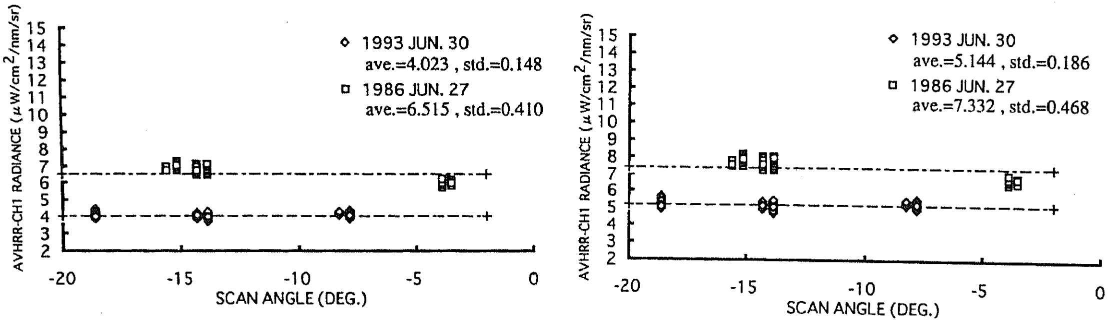
From above experimental results, it is obvious that the calibration considering the sensor degradation is necessary to derive an accurate radiance at the satellite observation. If the geometric condition is in a very good condition that the sensor scan angle is very small, the derived radiance by the above calibration and correction will be able to be used directly for the comparison of the ground surface between the plural data taken at different times.

Actually, it is impossible to acquire all necessary data in a good geometric condition. Therefore the archived data like a mosaicked product at least should include the geometric information (solar and satellite zenith angles and solar-satellite relative azimuth angle) for every pixels, which might be used for a later atmospheric correction procedure if possible.

3. Effect of Solar-Sensor Geometry on Surface Albedo and NVI

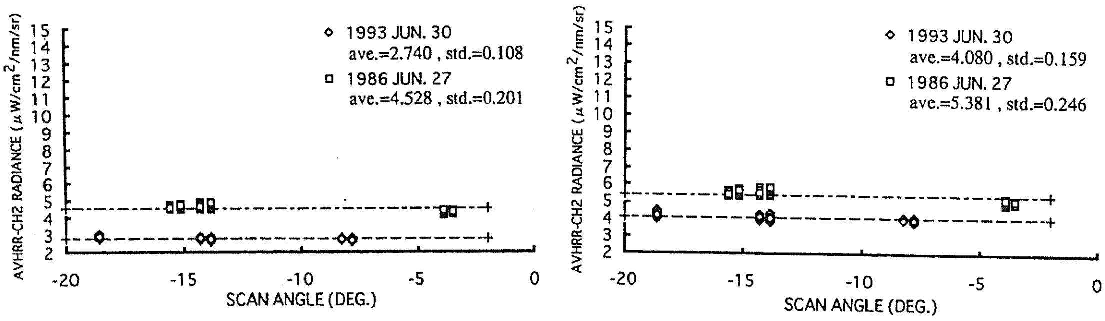
When the multi-temporal AVHRR data are used for the monitoring of land cover conditions, the effects of the geometric conditions among the sun, a sensor and a ground should be considered, because these conditions bring the change of the surface albedo and NVI derived from AVHRR data. In order to investigate these effects, three AVHRR data which were observed within a week and have different geometric conditions were used. The data were acquired on 6/Feb. (9303708), 7/Feb. (9303808) and 13/Feb. (9304409) in 1993 respectively.

Under the assumption that the ground surface conditions are same among the three, total 16 sample area triplets corresponding to the same location were selected. Each sample area was composed by 5 by 5 windows and the average value in the window was used as the representative data of the sample area. The land cover classes of the samples were forest, agricultural land and bare soil.



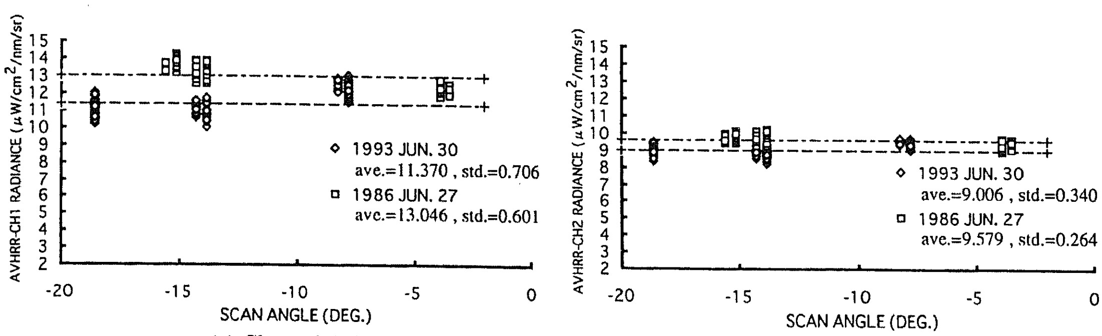
(a) Channel-1 data (b) Channel-2 data

Fig. 1 Result of preflight calibration.



(a) Channel-1 data (b) Channel-2 data

Fig.2 Result of the calibration considering sensor degradation.



(a) Channel-1 data (b) Channel-2 data

Fig.3 Result of solar zenith angle correction after the calibration of Fig.2.

3.1 Relation between surface albedo and geometric condition

Fig.4(a - e) shows the values of the samples for solar zenith angle, satellite zenith angle, albedo in CH.1 and CH.2, and the normalized vegetation index (NVI) derived as follows;

$$NVI = (A2-A1)/(A2+A1) \qquad (4)$$

where A1 and A2 are the albedos in CH.1 and CH.2 respectively. The sign of the satellite zenith angle was inverted when the solar azimuth and satellite azimuth is in a reverse direction, namely if the relative azimuth of the two is larger than 90 deg..

It is obvious that the variations of the albedos in CH.1 and 2 are clearly related to the two geometric parameters, the solar zenith and satellite zenith angles. Because the albedo is derived after the solar zenith angle correction described in 2, The main parameter affecting the albedo is considered to be the satellite zenith angle. Generally, the albedo becomes larger in the case of positive large satellite zenith angle, namely in the case of large satellite zenith angle in the same direction of the sun and a satellite. It is obvious that this variation is caused by the larger effect of the path radiance. On the contrary, in the case of small positive values and negative values of the satellite zenith angle the variation of the albedo is smaller.

On the other hand, the variation of NVI is rather reverse of that of the albedo, namely NVI decreases in the case of positive large satellite zenith angle. For the data 9303708 and 9303808, the NVI values are almost similar except the sample 6, which is the bare soil surface and has the positive large satellite zenith angle.

3.2 Regression analysis of albedo and NVI between two different data

Fig.5 shows the results of regressions of the albedos and NVI between two different data. The results show that the correlation coefficient for the pair of 9303708 and 9303808 is always larger than that for the pair of 9304409 and 9303808 for both of albedo and NVI. Therefore it is obvious that the data in the geometric condition of positive greater satellite zenith angle degrade the linearity of the correspondences of albedo and NVI with other data.

As to NVI, in the pair of 9303708 and 9303808 almost of the samples are in a region of acceptable variations of NVI for the comparison even if there remains relatively large variation in albedo. This result suggests some effect of NVI for the compensation of the variation due to the geometric conditions. However, for the pair of 9304409 and 9303808, almost of the samples result in under estimation of NVI for one of the pair, 9304409. In this sense, the samples from 9304409 have quite poor quality for the comparison with others, even if the NVI is used for the comparison.

3.3 Discussion

From the above results, it is obvious that the geometric condition, especially the satellite zenith angle brings the large effect on surface albedo and NVI, not only to the absolute values but also the linearity of data correspondences even after a linear data conversion. The NVI is less affected by the geometry compared with the albedos in CH.1 and 2, which has proved some

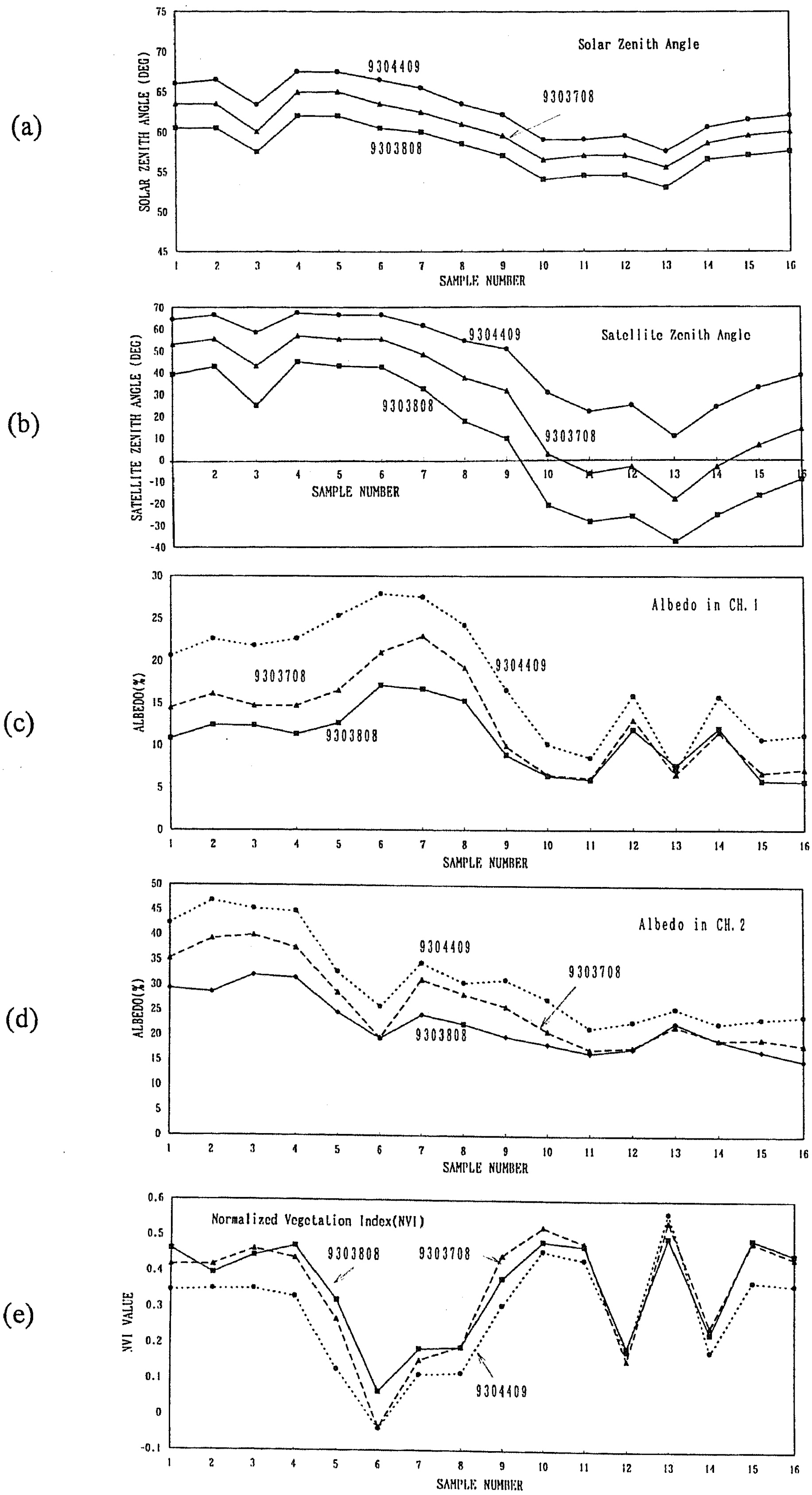


Fig.4 The values of solar zenith angle(a), satellite zenith angle(b), albedo in CH.1(c) and CH.2(d) and NVI(e) of all the samples of the three different AVHRR data.

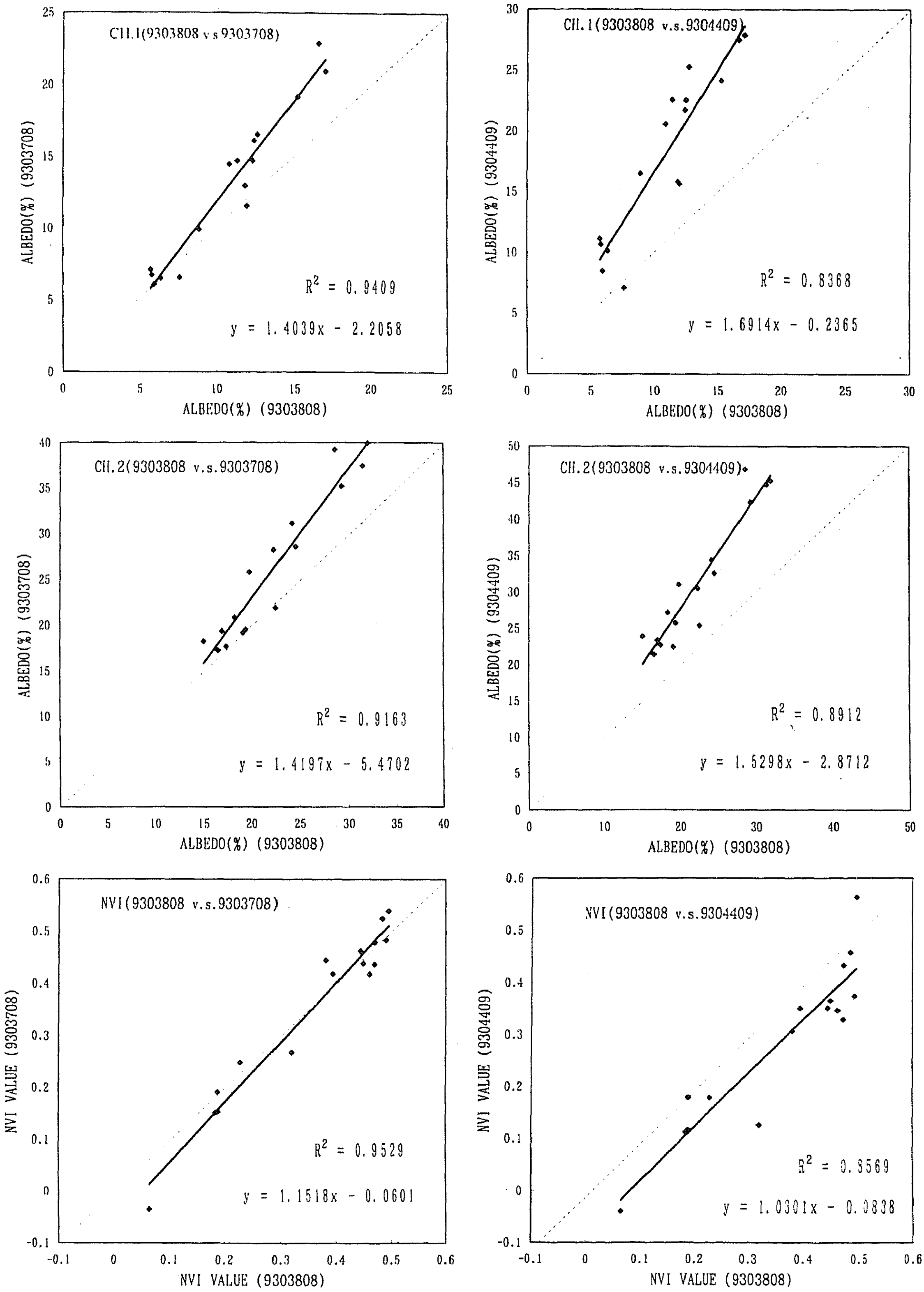


Fig.5 Results of the regression of the albedo in CH.1 and 2 and NVI between two different data (9303808 v.s. 9303708 and 9303808 v.s. 9304409).

effect of the NVI for compensation of unexpected variation of surface albedos. However, if the satellite zenith angle is much larger than an acceptable value, may be 50 degree from Fig.4, it is recommended not to use that sample for the comparison with other data. If only the data sample in such a bad condition is available, it should be recognized that the NVI values are always under estimated compared with the real values.

4. Conclusion

The effects of the sensor degradation and the geometric conditions related to the sun, a satellite and a ground were studied in the situation of the comparison of multi-temporal AVHRR data. The calibration considering the sensor degradation was proved to result in more appropriate correction for the comparison of the AVHRR radiance derived from different satellites. The geometric parameter, especially the satellite zenith angle was proved to have the large effect on albedo and NVI derived from the calibrated AVHRR visible and near IR data.

The ideal case seems to be that an appropriate atmospheric correction is applied to the calibrated data based on the geometric parameters computed in the calibration procedure. However, even if the atmospheric correction is difficult to be applied, at least these geometric parameters should be always taken into consideration for the comparison among the multi-temporal AVHRR data. This consideration may be useful to avoid misunderstanding about the temporal change of ground surface conditions.

References

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2) B.N.Holben,Y.K.Kaufman and J.D.Kendall(1992),NOAA-11 AVHRR visible and near-IR inflight calibration, INT.J.REMOTE SENSING, Vol.11,No.8, 1511- 1519.