Reprinted from

Eighth International Symposium

Machine Processing of

Remotely Sensed Data

with special emphasis on

Crop Inventory and Monitoring

July 7-9, 1982

Proceedings

Purdue University
The Laboratory for Applications of Remote Sensing
West Lafayette, Indiana 47907 USA

GEOMETRICAL AND ATMOSPHERIC CONSIDERATIONS OF NOAA AVHRR IMAGERY

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ABSTRACT

The Advanced Very High Resolution Radiometer (AVHRR) on the National Oceanic and Atmospheric Administration (NOAA) satellites NOAA-6 and NOAA-7 have good potential for use in the area of crop monitoring. Channels 1 and 2 of the sensor are, spectrally, very close to bands 5 and 7 of the Landsat multispectral scanner (MSS). The daily global coverage which can be obtained from these satellites makes this monitoring role feasible. However, the low resolution (1.1 kilometre) and large scan angle (approximately $\pm 56^{o}$ from nadir) lead to some data interpretation problems. Within this paper the effect of large scan angles and the subsequent effects of the atmosphere are investigated. It was found that there are substantial day-to-day variations in the data that are not related to crop condition. Procedures, using the within scene radiances have been developed to remove these radiance variations which are caused by the illumination/view geometry and atmospheric path radiance.

RESUME

Le radiomètre à très haute résolution (AVHRR) monté à bord des satellites NOAA-6 et NOAA-7 (National Oceanic and Atmospheric Administration) possède un bon potentiel d'utilisation pour la surveillance des cultures. Les canaux 1 et 2 de ce radiomètre sont spectralement très proches des canaux 5 et 7 du balayeur multispectral de Landsat (M.S.S.). Le rôle de surveillance des cultures est favorisé par la couverture journalière qu'offrent les satellites NOAA. Cependant, des problèmes d'interprétation de données apparaissent vu la faible résolution du détecteur (1.1 k.) et le grand angle de balayage (approximativement $\pm 56^{o}$). Les déformations causées par ce dernier et leurs effets sur l'atmosphère sont discutées dans cet article. D'importantes variations, de jour en jour, des valeurs de radiances qui ne sont pas reliées aux conditions des cultures, ont été notiés. Afin d'éliminer ces variations qui sont dues aux conditions d'illumination, à la géométrie de visée et à la radiance de parcours de l'atmosphère, une méthode se servant des valeurs de radiances à l'intérieur d'une même scène, a été développée.

I. INTRODUCTION

Reliable monitoring of crop condition is an important requirement for countries whose gross national product is based on a substantial agricultural industry. It has been shown that Landsat multispectral scanner (MSS) imagery can be used to estimate crop condition but there are several limitations of these data (Thompson and Wehmanen, 1979). First, since Landsat has a spatial resolution of approximately 80 m, the data volumes involved in wall-to-wall coverage of large areas are enormous. Consequently, it is necessary to sample the area. In theory this is a good approach but in practice there are some serious limitations caused by the satellite characteristics. The approximate $\pm 6^{o}$ scan angle of the MSS results in near nadir data which need not be corrected for scan angle effects but it also limits the area coverage to approximately 185 km by 185 km. To cover the agricultural area of Southern Saskatchewan (analyzing only the sample segment data) requires data on each of 6 consecutive days. Since the satellite has a repeat cycle of 18 days, it is highly unlikely that data would be collected for each sample area even once a month because of the presence of clouds. Hence, although the Landsat MSS is excellent for detailed analysis of areas smaller in dimension than a swath width, it is not appropriate for continuous monitoring of crop conditions over major agricultural regions such as the Western Canadian prairies.

The Advanced Very High Resolution Radiometer (AVHRR) on the NOAA-6 and NOAA-7 satellites has the potential to become an effective complementary satellite to Landsat for this monitoring roles.

The AVHRR has two channels in the visible and the near-infrared portions of the electromagnetic spectrum that correspond closely to bands 5 and 7 of Landsat MSS. These bands have been used extensively in vegetation studies (Richardson and Wiegand, 1977). Since the NOAA-6 and NOAA-7 spacecrafts are at altitudes between 800 and 850 km and the AVHRR has a scan angle of approximately ±56° it is possible to acquire daily coverage of an area of interest. The instantaneous field-of-view of the AVHRR is approximately 1.1 km. It is possible to acquire a synoptic view of a large area, analyze it for anomalies, and to direct further detailed analysis which could be done using the Landsat MSS data if they are available.

The wide swath width and low resolution cause some problems in interpretation which are addressed in this paper. Correction procedures must be developed to account for varying atmospheric path radiances, variations in reflectances due to changes in scan angle and the fact that this sensor usually images mixed areas; that is the pixels are mixed pixels.

Within this paper procedures are specified for correcting for the path radiances effects and variations in reflectances due to varying scan angles. The corrections for mixed pixels will be addressed in a future paper.

II. STUDY AREA AND DATA COLLECTION

The southern part of the province of Saskatchewan was chosen for this study because of the extensive dry land farming which is carried out in the region and the availability of ground information. The area extends from the USA/Canada border (49° N latitude) to the Canadian Shield (54° N latitude) and covers an area of about 250,000 km^2.

Half of the study area is cultivated, 30% is covered by grassland and the rest is forested. Three major types of soil are found in the cultivated regions: brown, dark brown and black chernozem. The slopes are generally small (< 10%). The main crops include wheat, oats, barley, canola, and flaxseed with wheat predominating. Six sub-areas were selected within the region for extensive analysis. These were chosen to represent a cross section of different soil and climatic zones and land use. Figure 1 shows the locations of these sub-areas.

Imagery from the NOAA-6 AVHRR for 31 dates between May 23 and August 11, 1981 were analyzed on the CCRS Image Analysis System (Goodenough, 1979). All the test sub-areas were not cloud free on all of the images but approximately 20 to 25 clear images of each of these were available for subsequent analysis.

III. DATA ANALYSIS

It was apparent from our initial examination of the channels 1 and 2 radiance data from the NOAA AVHRR that there are substantial variations in the data that are not related to vegetation changes. Figure 2 is a plot of the radiance values for channels 1 and 2 as a function of time for test area number 5. The plots do not have the usual appearance of temporal plots of vegetation; namely, a well defined decrease in channel 1 (caused by chlorophyll absorption at 0.68 micrometres) and an increase in channel 2 (caused by increased infrared reflectances) as the amount of green vegetation increases.

In addition, we found that the radiance data were strongly dependent upon scan angle. Figure 3 is a plot of the AVHRR channel 1 radiance as a function of scan angle as measured from nadir for test area number 5.

A second order regression line has been placed through the data with a resultant coefficient of determination of 0.92 (16 points). Only data for days after day 170 (June 19) were used in this analysis so that phenological development effects were minimized. We found that for all of the test areas there was a significant linear correlation between the AVHRR channel 1 and channel 2 data. Other studies (Shlien and Goodenough, 1973; Staenz et al., 1980) have shown that there is little correlation between bands in these two spectral regions. Table 1 shows the coefficients of determination for the linear correlations between the channels 1 and 2 radiance values. It can be seen that these coefficients vary from 0.30 to 0.66. This high correlation between these two spectral regions is not caused by the reflection of the sun's illumination by the vegetation and hence, must be caused by other factors such as atmospheric path radiance and angular reflectance effects.

Several approaches were used to correct for the atmospheric effects. The first procedure (correction procedure 1) was to measure an atmospheric path radiance and subtract this from the measured radiance. The atmospheric path radiance was estimated by looking at the radiance values from the lakes in the Canadian Shield which is just to the north of the agricultural area in Saskatchewan. In this procedure the water radiance was measured as a function of scan angle. The water radiance value corresponding to the scan angle of the test area was then subtracted from the area radiance value.

Figure 4 is a plot of path radiance versus scan angle for clear deep water bodies. If θ_1 is the scan angle of the test area, the path radiance correction ab would be subtracted from the radiance value for the area. This approach has several inherent assumptions and operational difficulties. One assumption is that the atmospheric conditions over the Canadian Shield clear lakes are the same as over the agricultural areas to the South. This is probably only valid as long as the scene is very clear. A correction could, however, be made for any variations if there is a clear deep body of water in the vicinity of the test area. Knowing the scan angle position of this water body the radiance of this water could be compared to the radiance of that measured for the water bodies of the Canadian Shield. If the two values did not agree, an adjustment for the baseline or nadir radiance could be made. Again referring to Figure 4, still assume that θ_1 is the scan angle of the test area and also that at θ_2 there is a clear lake near the test area. cd is the amount that this lake radiance is above the water radiance curve generated for the Canadian Shield lakes. This implies that the atmosphere is more hazy in the vicinity of the test area and hence an addition correction cd is subtracted from the area radiance (R). That is the corrected radiance (R^1) becomes:

$$R^1 = R - ab - cd$$

This approach assumes that the variations of path radiance with scan angle follow parallel but displaced curves for different atmospheric conditions.

One operational problem which arises with such an approach is that the Canadian Shield area may be cloud covered but the agricultural areas may be clear and hence it would not be possible to get the correction curve. In this case an aggregate curve from several different days could be used to make a cd correction. However, this approach has several deficiences. One, there is no correction for sun elevation angle changes. The extent that such variations affect the path radiance will depend upon the angular scattering properties of the particles in the atmosphere. This is of course dependent upon the atmospheric conditions which are not known. Also, there is no correction being made for the variations in vegetation reflectance with scan angle. These can be substantial; from 10 to 30% for scan angle changes of $\pm 20^o$. (Staenz <u>et</u> <u>al</u>., 1981). Consequently, we decided to use a correction procedure which would incorporate these vegetation reflectance variations.

One approach (correction procedure 2) was to generate a curve of area radiance versus scan angle for all dates greater than day 170 (June 19). This date was chosen so as to reduce major phenological development variations. This curve was then used to correct the test area radiance values back to a nadir value. This procedure appears to work well but requires that historical data be available for the area in order to generate the area radiance versus scan angle curve. At this point there has been no correction for day-to-day variations in path radiance which could presumably be done using a similar correction procedure as that outlined previously for the water radiance. However, we did not pursue this approach in favour of a within scene correction procedure.

This within scene correction approach (correction procedure 3) accounts for scan angle, illumination geometry, and atmospheric condition (path radiance) variations. In this approach the radiance data for the particular date is used to correct the data. First a cursor of 20 pixels by 500 lines is moved through the image to generate a radiance versus scan angle curve for the agricultural area. If the agricultural test area is at scan angle θ_1 in Figure 5 then the correction AB (from this Figure) is applied to the measured radiance (R) to arrive at a corrected radiance R^1:

$$R^1 = R - AB$$

This corrects our radiance back to a nadir radiance. However, there can still be variations due to changing atmospheric conditions from day-to-day. To make a correction for this we measured the water radiance in an area near the test area, and made a correction for path radiance back to nadir in order to compare the nadir radiances from scene to scene. An adjustment was then made to the corrected radiance (R^1) so that the base line path radiance against which all were measured was the same. For example if Y_1 and Y_2 were the water radiance values at nadir for days 1 and 2 respectively, then a correction $Y = Y_2 - Y_1$ would be applied to R_2 so that the radiance values from the two days could be compared directly. Figure 6, shows a plot of the AVHRR channel 2 radiance values for the raw data, the raw data with just the scan angle correction (first part of correction procedure 3), and the raw data with the full correction procedure 3. It can be seen from this Figure that the raw data variations are considerably reduced.

IV. CONCLUSIONS

The NOAA AVHRR has the potential for being a complementary sensor to the Landsat MSS; the AVHRR to provide a synoptic view and the MSS to provide the data for detailed analysis. The large scan of the AVHRR causes some problems in the analysis procedures. There are wide variations in the day-to-day radiance values from our test areas caused by atmospheric and scan angle effects. Procedures have been developed which can remove these variations which are not related to crop condition.

V. REFERENCES

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VI. ACKNOWLEDGEMENTS

1. The authors would like to acknowledge the Atmospheric Environment Service, of the Canadian Department of Environment who supplied the NOAA AVHRR data.

2. The authors would like to acknowledge the financial inputs to this project from Statistics Canada, the Canadian Wheat Board and Agriculture Canada.

3. The authors would like to acknowledge Dr. P.M. Teillet and Dr. B. Guindon who developed the software for correcting for scan angle variations in the radiance values of airborne imagery which we used in our within scene correction procedure.

Coefficients of Determination

Test Area	Raw	Correction 1	Correction 2	Correction 3
1	.30 (28)	.01 (24)	.11 (28)	.39 (9)
2	.57 (27)	.08 (26)	.06 (27)	.39 (9)
3	.55 (24)	.17 (22)	.04 (24)	.05 (9)
4	.32 (27)	.02 (25)	.11 (27)	.13 (9)
5	.64 (21)	.10 (21)	.02 (21)	.07 (9)
6	.66 (24)	.14 (24)	.01 (24)	.01 (9)

Table 1: Coefficients of determination for linear correlation between the AVHRR channels 1 and 2 radiance values. The number in brackets are the number of points used in the calculation.

Correction 1: Procedure using water radiance data alone.

Correction 2: Procedure using a regression curve of radiance versus scan angle for all dates greater than day 170.

Correction 3: Procedure using within-scene radiance data and water radiance data.

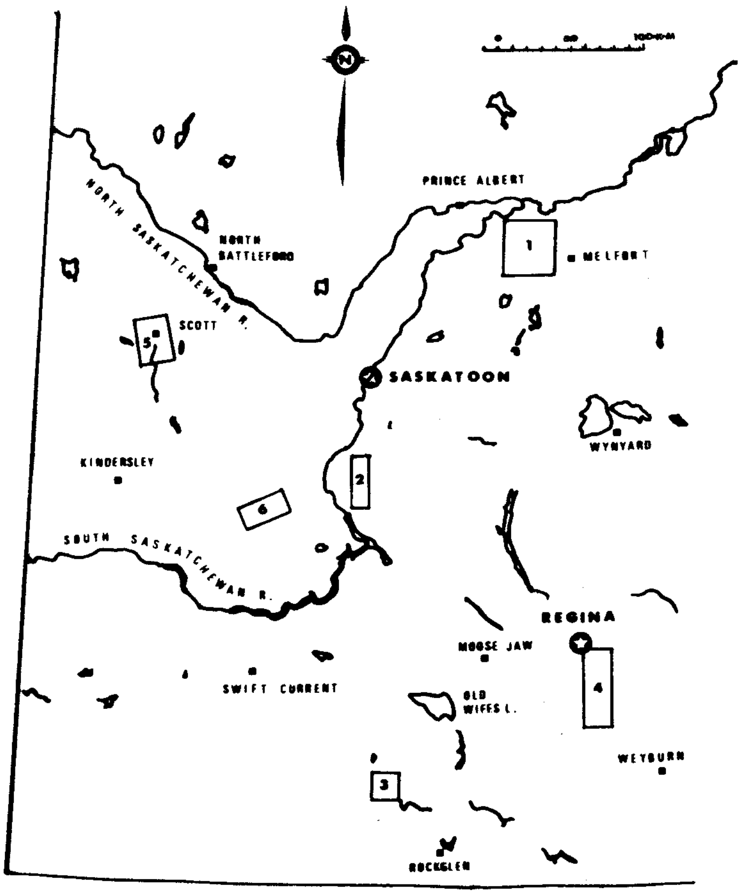

FIGURE 1. Sub-areas chosen for intensive analysis of NOAA data.

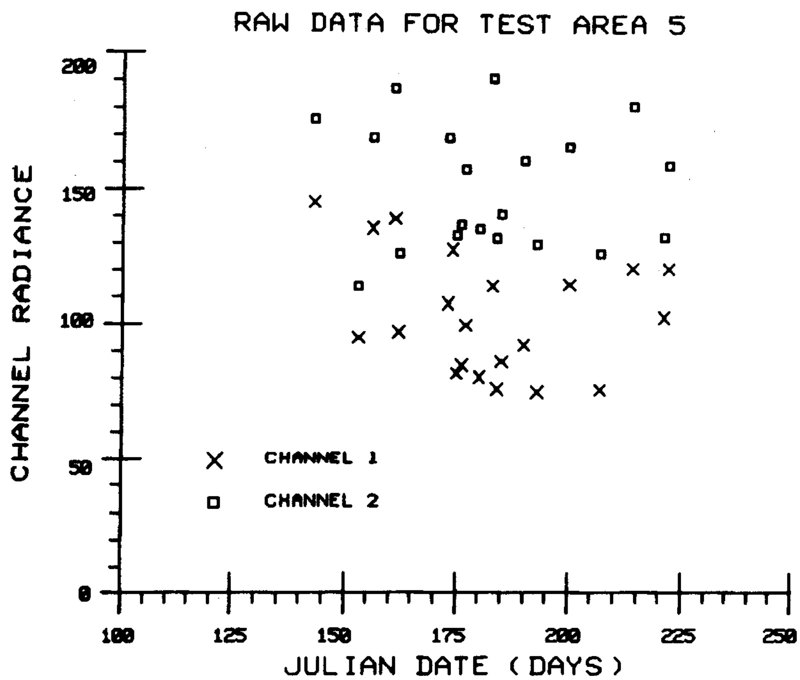

FIGURE 2. Raw AVHRR channels 1 and 2 radiance values as a function of time.

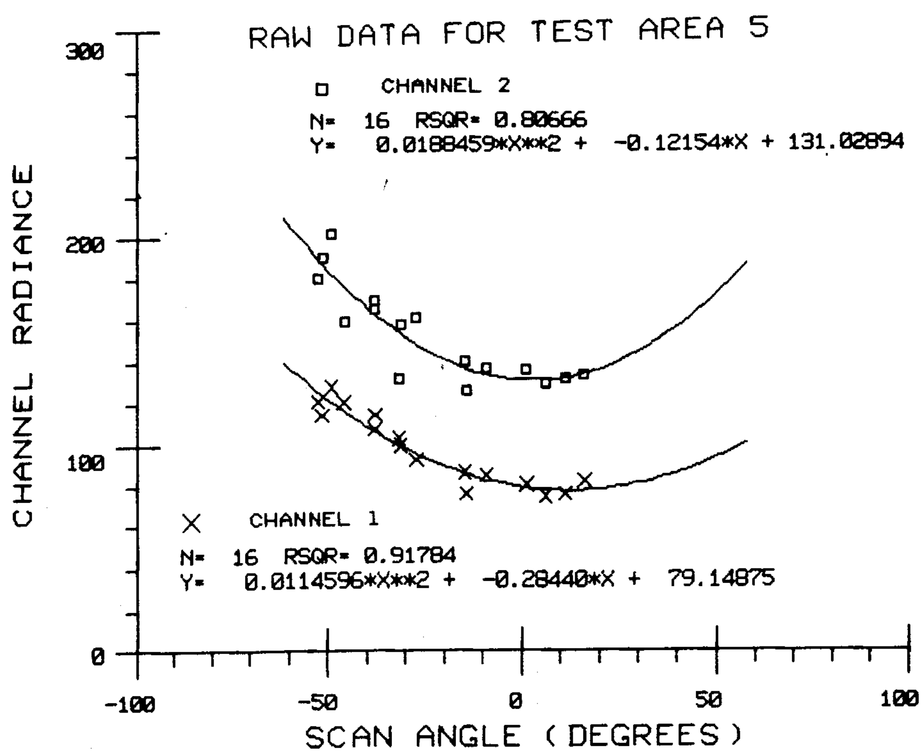

FIGURE 3. Raw AVHRR channels 1 and 2 radiance values as a function of scan angle.

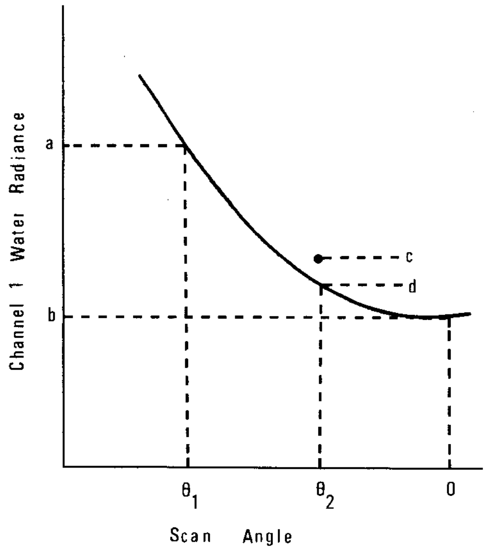

FIGURE 4. Water radiance values as a function of scan angle for three dates (June 2, July 10 and July 26, 1981).

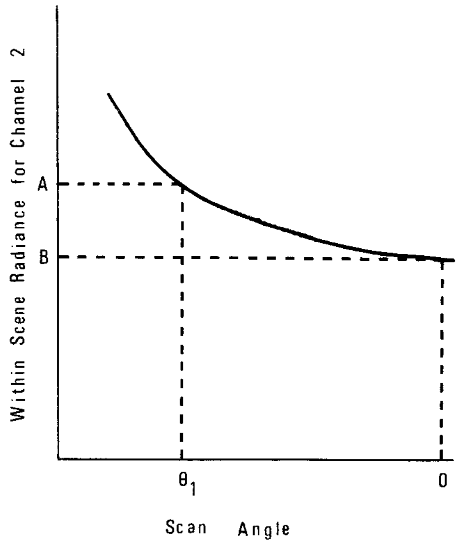

FIGURE 5. Within scene corrected AVHRR channel 2 radiance values as a function of scan angle for test area 1 on July 26, 1981.

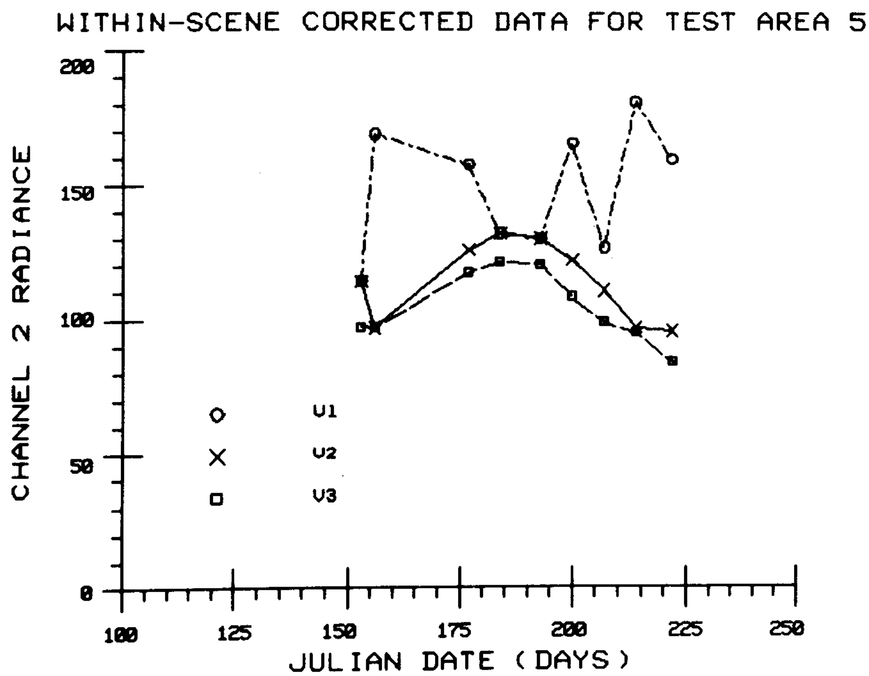

FIGURE 6. Test area AVHRR channel 2 radiance values as a function of time
V1 ≡ raw data
V2 ≡ within scene radiance correction
V3 ≡ within scene radiance correction plus atmospheric adjustment using water body radiance values.