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INTEGRATION OF HIGH AND LOW RESOLUTION SATELLITE DATA FOR CROP CONDITION ASSESSMENT

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ABSTRACT

LANDSAT multispectral scanner (MSS) and NOAA Advanced Very High Resolution Radiometer (AVHRR) imagery were registered and the radiances from several sites were measured. The LANDSAT data were used to assess which ground cover types were contributing to the AVHRR radiance values and to evaluate the effect non-grain classes would have on estimating grain crop condition. It is seen that great care must be taken in directly comparing areas within one data source with different crop mixes and vegetation classes since the total contribution of the grains to the vegetation index, as measured by the AVHRR, can be less than 40%. However, reliable use can be made of the AVHRR data if a comparison is made from year to year for a particular region.

I. INTRODUCTION

Since the launch of the first LANDSAT satellite in 1972, there has been a great deal of interest in using satellite imagery for agricultural applications and particularly as an input to crop information systems. Most initial agricultural studies have focussed on the information content, within the imagery from the multispectral scanner (MSS) abroad this satellite, for crop area and crop condition assessment. For example, it has been shown that various vegetation indices formulated from these data correlate with measurable crop properties such as leaf area index or biomass (Wiegand et al., 1979; Aase and Siddoway, 1980; Tucker et al., 1980). Others such as Kanemasu et al. (1977) and Heilman et al. (1977) have gone one step further by using the estimates of crop parameters, derived from the LANDSAT data, as input to evapotranspiration models. Finally, studies by Mack et al. (1977), Colwell et al. (1977), Barnett and Thompson (1982), and Idso et al. (1978) have shown a more direct relationship between vegetation condition and spectral data. For example, Thompson and Wehmanen (1979) used a Green Number Index to detect and monitor vegetation water stress. This index, obtained by subtracting a soil line from the Greenness (Kauth and Thomas, 1976), was found to correlate with drought conditions. In a subsequent paper Barnett and Thompson (1982) found a weak linear correlation between the average yield for 30 crop reporting districts in the USA Great Plains and a Green Index Number in moderate to severe vegetation stress conditions.

One of the main impediments to the inclusion of MSS data in operational programs has been the availability of timely imagery. LANDSAT, with its 16-or 18-day repeat cycle (depending on the satellite) usually cannot ensure that data will be routinely available because of the high probability that cloud will obscure the earth from the MSS on any given pass. For example, in Western Canada, Clough et al. (1983), estimated the probability of acquiring a specific LANDSAT frame with less than 20% cloud cover in July is about 29%.

As a result, in 1981, we began an investigation to determine the extent to which low resolution imagery from the Advanced Very High Resolution Radiometer (AVHRR) carried on board the National Oceanic and Atmospheric Administration (NOAA) satellites could be used to assess crop condition over a large area in a timely manner. Since the AVHRR has a very large scan angle of ± 55.4° from nadir, this instrument is capable of imaging every agriculturally significant area of the earth daily. Moreover, starting with NOAA-6 (launched in 1979) there was a change in spectral band allocations such that channels 1 and 2 of the AVHRR approximated bands 5 and 7 of the LANDSAT MSS, which have been used extensively for vegetation studies. Table 1 gives a comparison of the AVHRR and MSS and the characteristics of their satellite platforms.

Allowing for data losses due to cloud cover, it now becomes highly probable that imagery can be acquired for most agricultural areas on a weekly basis and thus meet the timeliness requirement for vegetation monitoring. However, the spatial resolution of the AVHRR is drastically reduced from that of the MSS. Furthermore, the introduction of the wide scan angle results in significant radiometric and geometric distortions. With a spatial resolution of approximately 1.1 km at nadir it is not possible to image individual fields; rather the AVHRR records the overall radiance or reflectance from an area. The question then arises whether these values can be related to vegetation conditions. We have looked at this in some detail using LANDSAT MSS imagery and have found a strong correlation between overall scene radiance and the average radiance from grain fields within the area from which the overall scene radiance was collected (Brown et al., 1982b). In essence this means that if the grains are doing well within an area then other crops, including native vegetation, will also be doing well. The work by Mack et al. (1977) also supports this positive correlation between vegetation condition of different plant species.

Since this correlation between grains and overall scene radiance was carried out using LANDSAT MSS imagery, and MSS data is collected within ± 6° of nadir, scan angle effects were not prominent. However, when actual AVHRR imagery is used scan angle and solar illumination effects cannot be neglected (Brown et al., 1982a). Within that paper it is shown that plots of AVHRR channel 2 data did not follow the expected vegetation development curve, namely, a sharp rise as the vegetation starts to turn green in the spring followed by a decline after the cereal crops have headed and begun to ripen. However, after applying an empirically derived correction factor for the scan angle and illumination effects the data within an image at different scan angles could be directly compared. This correction factor was generated by measuring the scene radiance (within a cursor that was narrow in the cross track direction and long in the along track direction) as a function of scan angle, and then fitting a second order polynomial to these radiance values. A final radiometric correction was made to account for day-to-day variations in path radiance and atmospheric transmission. This was done by measuring the radiances of water bodies and clouds within the scene and applying a gain and offset correction so that these two targets always had the same digital counts.

Since the radiances recorded by the AVHRR sensor represent a large area and each pixel is most likely a mixed pixel the average radiance from an area will depend on the crop mix. Consequently, care must be taken when comparing radiance values between two areas with, for example, differing amounts of summerfallow. Using multiple linear regression analysis Brown et al. (1985) have shown that vegetation parameters such as the peak of the normalized difference (AVHRR channel 2 and channel 1) curve plotted against time or the area under this curve is highly correlated to the percentage of summerfallow within the area. This is not unexpected, since a high percentage of summerfallow would definitely reduce any vegetation index because, to the AVHRR, summerfallow would appear as an extremely poor crop.

In this paper we will present results illustrating the contribution of the various vegetation classes to the overall vegetation index recorded by the AVHRR and suggest how an integrated LANDSAT MSS and NOAA AVHRR data set can be used to improve data interpretation.

II. TEST SITES AND DATA SET

Three test sites approximately 25 km by 35 km in size within an area to the north west of the city of Saskatoon, Saskatchewan were selected for this study. These sites are shown in Figure 1. Site number 3 is located within the Black Soil Zone, where there is likely to be more canola, more bush land, and less summerfallow than within sites 1 and 2 which were within the Dark Brown Zone. It should be noted that there is not an abrupt transition from Dark Brown to Black soils.

A NOAA-6 AVHRR image from August 1, 1984 and a LANDSAT-5 MSS image from July 27, 1984 were used in the analysis. The NOAA AVHRR image was recorded at 14:22 Z or 8:22 CST at which time the solar elevation and azimuth angles were 24.6° and 92.1° respectively. This AVHRR image was corrected for radiometric distortions caused by the wide scan angle and non-Lambertian reflectance properties of the terrain (Brown et al., 1982a). These two images were then geometrically registered to an accuracy of ± 250 m.

The test sites were located by visually examining the NOAA AVHRR imagery and selecting agricultural areas which had no apparent water bodies, rangeland, forested areas and river valleys. Crop condition was estimated from final wheat yields for the rural municipality (RM) within which these sites were located. These RM yield values were supplied by Statistics Canada. These yield values should be considered as only indicators since in many cases the statistical sampling density is not sufficiently dense within an RM to give a reliable absolute yield value. However, it is felt that the relative RM yield values, one to the other, are correct.

III. RESULTS

As mentioned previously our analysis (Brown et al., 1985) has shown a strong correlation between various vegetation indices derived from AVHRR channels 1 and 2 and yield provided corrections are made for differing percentages of summerfallow between areas. Within the present study we have examined more carefully which terrain types are likely to be confused with cultivated land and how this will affect the AVHRR channel 2/channel 1 ratio and any subsequent correlation of this vegetation index to crop condition.

Radiance values for the AVHRR channel 2/channel 1 and the LANDSAT MSS band 7/band 5 (B7/B5) ratios were measured for the three test sites. For LANDSAT this ratio was calculated for the whole test site as well as for the individual terrain and crop types within it. Table 2 gives the NOAA AVHRR channel 2/channel 1 ratio for the three test sites along with the estimated RM wheat yield values. This table shows that the highest AVHRR channel 2/channel 1 ratio does indeed correspond to the site with the higher yield and the lower values to the sites with the lower yields.

Consider now the LANDSAT MSS B7/B5 ratio to estimate what contribution the various vegetation classes make to the AVHRR ratio and assess the reliability of this encouraging correlation between vegetation indices, derived from low resolution NOAA AVHRR imagery, and crop condition.

Table 3 gives the LANDSAT MSS B7/B5 ratios for these three sites and a breakdown of the various classes which were found within them. The overall B7/B5 ratio for each of the sites is the sum of the B7/B5 ratio for each of the individual classes within the site weighted by the percentage of each of these classes. The contribution of each of the individual classes to the overall ratio (given in the last column of Table 3) is the class B7/B5 weighted by the percentage of the class within the site (product of columns 3 and 4 of Table 3) divided by the overall ratio. Sites 1 and 2, which have approximately the same yield, have also approximately the same value for the LANDSAT B7/B5 ratio for the grain class (66.5 ± 19.3 versus 69.3 ± 18.1 for sites 1 and 2 respectively) while the value for site 3 is substantially higher, 112.0 ± 17.9, with an accompanying higher yield of 4 to 5 bu/ac over the two sites. Comparing the overall B7/B5 ratios (average of all the pixels within the test sites regardless of class) for the sites shows that sites 1 and 2 do have essentially the same values 59.0 versus 59.4, while the value for site 3 is substantially higher at 89.4. Again this is consistent - that is, a higher ratio for the better yield area. For sites 1 and 2 the spatial area of the grains corresponded to 47% and 44% respectively while for site 3 the corresponding value for the grains was 30%. Moreover, the contribution of the grains to the overall B7/B5 were 53.0, 51.5 and 37.6% respectively for sites 1, 2, and 3. The question arises - can estimates of crop condition and projected final grain yields be made using a NOAA AVHRR vegetation index when only 38% of the contribution to the index is from the grains? An examination of the other crops shows that this is possible and indicates why this is so. First consider pasture. The B7/B5 ratios for this terrain type is 51.0, 54.6, and 63.8 for sites 1, 2, and 3 respectively. Thus within the area where the grain yield is higher the radiance values of the pastures are greater which could be caused by either better soil or a better distribution and magnitude of rainfall. This supports the hypothesis that if one type of vegetation is growing well so are other similar vegetation types. Pasture land will be less affected by variations in precipitation amount because of its better defined root structure but there should still be an effect on pasture development caused by decreased precipitation. When pasture lands are included with the grains the total contribution to the band ratios became 69.4, 76.5, and 44.0 respectively for sites 1 to 3 and the corresponding spatial extent of the grains plus pasture within the sites is 66%, 71% and 39%.

Within all the areas there is approximately the same amount of summerfallow which contributed from 8.3 to 11.6% to the total B7/B5 ratio. Hence considering grains, pasture and summerfallow we find that the total contributions to the B7/B5 ratio are 81%, 86.6% and 52.3% for sites 1 to 3 respectively. The area planted to grain or left fallow does not vary considerably from year to year but in any case a variation of 5% in the relative amounts accounts for only 2.7, 2.8 and 3.6% variations in the total B7/B5 ratio and hence would not affect the total drastically. This percentage reduction was calculated by increasing the percentages of summerfallow by 5% and decreasing the percentage of grains by a corresponding 5% (values given in column 3 of Table 3) and calculating the resultant change in the overall B7/B5 ratio.

Considering summerfallow and grains in a single category, it might be possible to estimate production. Production is usually the desired figure rather than individual values of yield and area. More summerfallow would lower the spectral ratio with a subsequent reduction in production but not necessarily in yield.

Now consider the contribution of the remaining terrain classes to the overall LANDSAT B7/B5 ratio. Within site 1 irrigated land, wooded areas, and water make up only 2.1% of the area and contribute only 3.4% to the overall B7/B5 ratio. The residual class is really not independent of the other classes. Since in general this is a mixed pixel with a vegetation component it should respond at least in the same direction as the vegetation classes with factors affecting vegetation vigour. Similarily at site 2 water and wooded areas make up 1.0% of the area and contribute 1.5% to the overall vegetation index and the same comment holds for the residual class. A large percentage of irrigated land could have a substantial effect on the overall, or NOAA AVHRR, band ratios. We have found, however, that such areas are distinguishable on the AVHRR and can be avoided if the objective is to assess crop condition in the dry land farming areas. Hence for these two sites the majority of the area responds to improved crop condition with increased vegetation index values.

Site 3 is somewhat different since it contains 11% woodland, 9% regenerated woodland and 4% canola all of which have B7/B5 ratios larger than grains within sites 1 and 2. These classes normally occur in areas with greater average precipitation. Furthermore, these woodland classes have a well established deep root structure and are less affected by annual precipitation variations than the annual grains. Their contribution to the overall B7/B5 ratio acts to accentuate the vegetation index between areas of different average precipitation and resultant different average yields. This illustrates the need for caution in the comparisons of the expected yields for areas of drastically differing soil/precipitation characteristics. It should be quite valid to compare radiances values from different years for the same agricultural area provided corrections have been made for atmospheric effects. This is possible since the non-grain contributions to the band ratio are either stable (wooded areas) or are vegetation related (mixed pixels) and respond in the same direction as pure vegetation pixels in a stress condition such as caused by lack of adequate moisture. Consequently, it should be possible to use the NOAA AVHRR channel 2/channel 1 ratio as an indicator of crop condition.

This study was carried out in an area where there is a high correlation between pedology and climatology. That is the soil type is governed to a high degree by the climate. However, if we were to transfer the techniques to eastern Canada, where there are abrupt changes in soil type, and, consequently, less correlation between climate and pedology the correlations which have been found between grain yields and NOAA AVHRR may be less distinct. This would occur because factors , such as bushland, would be present in both areas and hence differences in AVHRR radiances due to crop condition differences may be small.

IV. CONCLUSIONS

Even though the percentage area of grains can be less than 50% of the total land area, NOAA AVHRR data appears able to give consistent information on the changes in crop condition from year to year. From an analysis of LANDSAT MSS data it has been shown that average vegetation indices for a large area correlate to average grain yield values. For example, regions with greater amounts of average annual precipitation (and resultant higher average yield values) will have some wooded areas interspersed with the agricultural land which has the effect of increasing the vegetation indices. Hence, when comparing the AVHRR vegetation indices from areas with different crop mixes and terrain types corrections must be made for these differences. The LANDSAT MSS can be used effectively to carry out this evaluation of terrain classes.

In summary, NOAA AVHRR and LANDSAT MSS data complement one another. The AVHRR data gives an overview while the MSS provides more detailed information which can be used to develop correction factors to make the analysis of the AVHRR imagery more reliable. In particular, the LANDSAT MSS data can be used to identify those regions that can be directly compared and to specify the expected amount and identity of non-grain pixels within an area.

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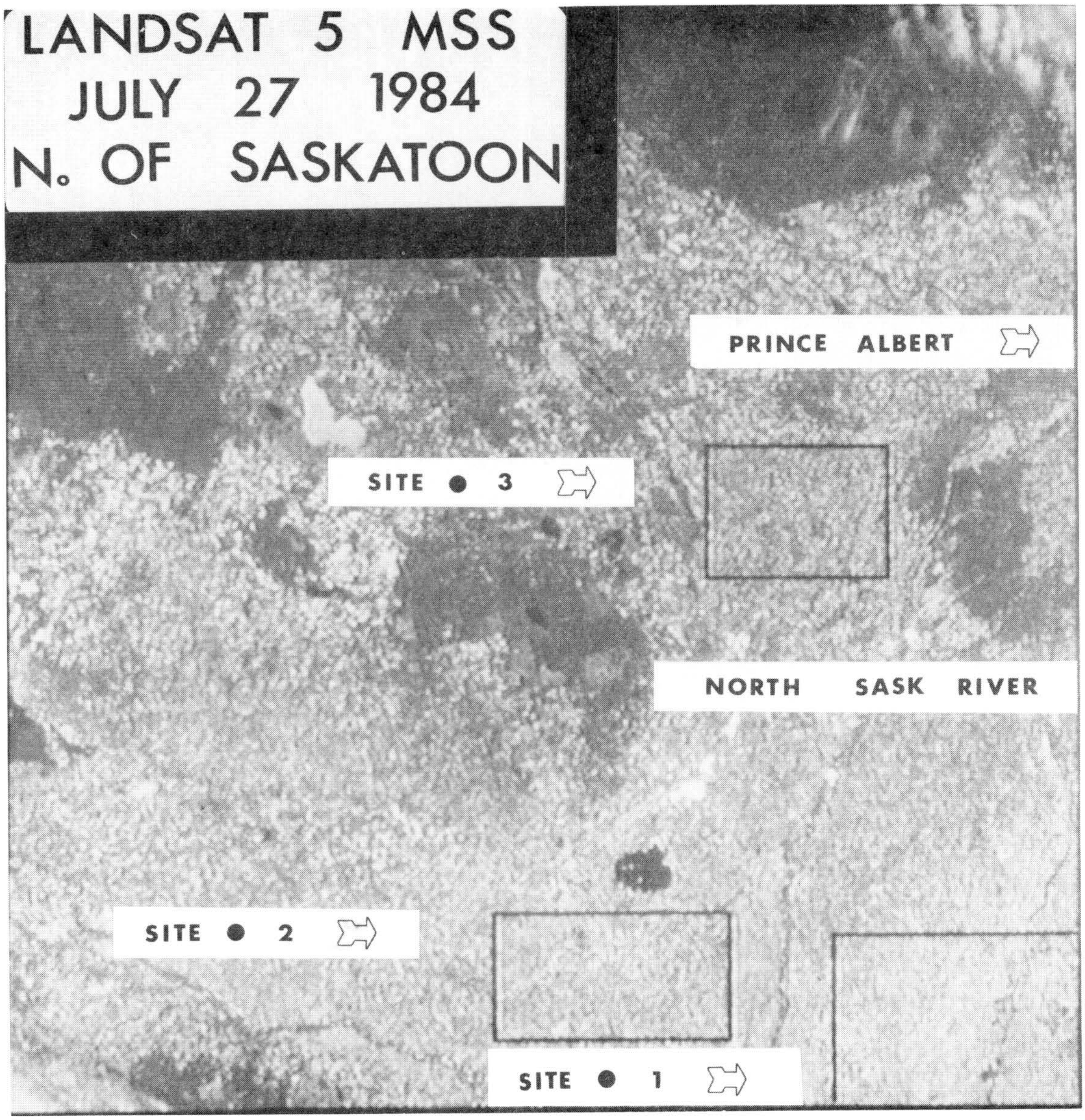

Figure 1. Location of the three test sites in northern Saskatchewan

Table 1. Satellite Sensor Characteristics.

	Sensor (Satellite)	
	MSS (LANDSAT-4)	AVHRR (NOAA-7)
Altitude	694 km	833 km
Type	polar orbiting	polar orbiting
Spectral Bands	0.5 - 0.6 μm 0.6 - 0.7 μm 0.7 - 0.8 μm 0.8 - 1.1 μm	0.58 - 0.68 μm 0.725 - 1.10 μm 3.55 - 3.93 μm 10.5 - 11.3 μm 11.5 - 12.5 μm
Ground Resolution	80 km	1.1 km
Swath Width	185 km	2500 km
Data Repeat	16 days	daily

Table 2. NOAA-6 AVHRR Channel 2/Channel 1 Ratios for three Test Sites in Saskatchewan on August 1, 1984.

SITE	AVHRR RATIO	ESTIMATED YIELD (BU/AC)
1	34.0 ± 3.8	22
2	33.9 ± 2.7	23
3	51.0 ± 4.3	27

Table 3. LANDSAT MSS Band 7/Band 5 Ratios for the Three Test Sites for July 27, 1984.

SITE	TERRAIN TYPE	SPATIAL EXTENT	BAND 7/ BAND 5	B7/B5 CONTRIBUTION TO OVERALL B7/B5
1	grains	47.0%	66.5 ± 19.3	53.0%
	pasture	19.0%	51.0 ± 9.6	16.4%
	summerfallow	19.0%	35.7 ± 3.4	11.6%
	irrigated land	0.8%	170.1 ± 24.4	2.3%
	wooded areas	0.3%	147.0 ± 16.4	0.7%
	water	0.9%	27.3 ± 14.9	0.4%
	residual	13.0%	70.6	15.6%
	overall	100%	59.0 ± 26.5	100%
2	grains	44.0%	69.3 ± 18.1	51.5%
	pasture	27.0%	54.6 ± 13.7	25.0%
	summerfallow	17.0%	35.0 ± 3.1	10.1%
	wooded areas	0.5%	123.4 ± 10.6	1.1%
	water	0.5%	30.3 ± 17.9	0.4%
	residual	11.0%	63.6	11.9%
	overall	100%	59.4 ± 22.2	100%
3	grains	30.0%	112.0 ± 17.9	37.6%
	pasture	9.0%	63.8 ± 6.4	6.4%
	summerfallow	16.0%	46.4 ± 10.4	8.3%
	water	4.0%	43.3 ± 22.9	1.9%
	wooded areas	11.0%	134.7 ± 23.1	16.5%
	regenerated wooded area	9.0%	83.4 ± 8.8	8.4%
	canola	4.0%	101.5 ± 11.7	4.4%
	residual	17.0%	86.7	16.5%
	overall	100%	89.4 ± 34	100%