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Study on Sensor's Spatial, Radiometric and Temporal Resolution Requirements for Crop Monitoring

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Abstract – **Effects of various sensor parameters such as spatial resolution, sensor radiometry and temporal resolution on crop monitoring on regional scale is reported. Results were interpreted for selection of optimal sensor parameters for Advance Wide field sensor (WiFS) slated for regional crop discrimination and high repetivity monitoring. Analysis was carried out using sensors on board IRS platforms (LISS-I, LISS-II, LISS-III, WiFS, MOS-B) and NOAA –AVHRR which covers spatial resolution from 23 meter to 1 km, Radiometry from 7 bit to 16 bit and temporal resolution from single day to 24 days. Requirement of spatial resolution of the sensor for crop identification/classification was evaluated based on the field sizes, local variance and crop classification accuracy. For crop discrimination and mapping of 2-3 ha field sizes, it was observed that spatial resolution of better than 70 meter would be needed. Sensor's radiometric influence was assessed on crop separability, classification accuracy and precision of crop NDVI. For monitoring the crop NDVI at precision better than 1 %, Radiometric resolution NEΔρ better than 0.3 % is suggested. Temporal resolution was assessed in reference to requirement of date of acquisition at peak vegetative stage and noise equivalent shift from peak (NEΔtp). It was suggested that revisit period of better than a week is needed for restricting the NDVI error less than 1 % due to acquisition date shift in wheat.**

Index Terms – **Indian Remote Sensing Satellite, Normalized Difference Vegetation Index (NDVI), Classification, Spectral Separability, Crop Growth Profile.**

I. INTRODUCTION

Starting with the first systematic attempt at making a crop inventory using Ariel remote sensing techniques in ARISE (Agricultural Resource Inventory Survey Experiment) project in 1974 [1] country has come a long way in Agricultural Monitoring and Modeling. Based on various agricultural applications different sensors have been developed and are being operationally used in India [2]. The Indian agriculture scene comprises multiple crops, sown under diverse agrometeorological conditions and cultural practices. Crops being the most dynamic land cover with a large spread in crop calendars and fragmented holding pose a challenge to remote sensing, making sensor optimum parameter definitions very complex. Attempt to arrive at the choice of sensor parameters for large area and repetitive monitoring of crops/vegetation for Wide Field Sensor (WiFS) type of sensor is reported here.

Choice of spatial resolution (SR) for remote sensing sensors has been one of the most crucial concerns for both users and designers. A number of studies have been made in past to assess the spatial resolution that are required for remotely sensed mapping and monitoring land cover transformation. It has been found by many workers that effect of spatial resolution in identification (classification) of land cover feature depend upon two conflicting parameters i.e. mixed pixels and scene noise [3]. If the spatial resolution is decreased, a large ground resolution elements are likely to include a greater proportion of boundary information and, secondly if the spatial resolution is increased the smaller ground resolution elements are likely to pick up the fine details of the field contents, resulting in increased spectral overlap (scene noise) between cover classes [4]. The crossover in the dominance of scene noise and boundary effect occur in the range of optimal spatial resolutions for a given objective and scale of estimation.

II. STUDY AREA AND DATA USED

A Study was carried out at two wheat growing regions of India viz. (1) Central Madhya Pradesh (M.P.) and (2) Punjab during the rabi season representing the multi crop heterogeneous as well as single crop homogeneous agricultural scene respectively. Spatial and temporal resolution requirements were studied in central M.P., where both wheat and gram crops are grown. Effect of spatial resolution on crop classification was evaluated on a test site of 10 X 10 km area of Tikamgarh district (M.P). The remote sensing data at different spatial resolution from various electro-optics sensors onboard Indian Remote Sensing (IRS) satellites [5] viz Linear Imaging Self Scanner (LISS) -III, LISS-II, LISS-I and Wide Field Sensor (WiFS) were acquired during Feb. 14, 1997 to Feb. 22, 1997 for this area. This data set spans a range of spatial resolutions from LISS-III (23 meter) to WiFS (188 meter), with simulated intermediate resolution from LISS-III (46 meter, 92 meter, 184 meter) and LISS-I data (142 meter). Wheat and gram reflectances were measured in Bhopal District of M.P. using field spectroradiometer for studing the effect of sensor radiometry. Temporal resolution was studies by ten day maximum value composite (MVC) NOAA Advanced Very High Resolution Radiometer (AVHRR) global data processed by IGBP at 1 km resolution after generating wheat growth profiles from Nov. 1992 – March 1993 for 12 districts of Central M.P. Test site of Punjab was used to study the effect of radiometric quantization on crop separability using Modular Opto-Electronics Scanner (MOS) -B imaging data onboard IRS-P3 satellite with 16 bit radiometric resolution and 520 meter (m) spatial resolution acquired on Feb. 13, 1997 [6]

III. METHODOLOGY

Spatial, Radiometric and temporal resolution were investigated using different approaches as described below.

A. Spatial resolution

Three approaches based on field size consideration, spatial variability and classification accuracy assessment were used for selecting suitable range of spatial resolution.

Consideration of field size: Maximum number of pixel that can be accommodated per field including the given border pixel and geometric error was computed for different field sizes based on expression proposed by Curran and Williamson [7].

Spatial variation : If SR is too fine then the information will be repeated and if the SR is too coarse then there will be the loss of information. Between these two extremes of information replication and information loss, there is SR at which the information in the scene is maximize without duplication. The local variance as an indicator of information was used for choice of spatial resolution and computed as

$$\text{Local variance} = 0.5 \, \Sigma \, (X_{ij} - X_{kl})^2 \, / \, n$$

Where X_{ij} is the gray value of central pixel of a small window: X_{kl} is the grey value of neighboring pixels in the window; and n is the number of neighboring pixel considered. The value of local variance in near infra red (nir) band was calculated for available and simulated spatial resolution from 23 meter (LISS-III) to 188 meter (WIFS).

Classification accuracy: Classification accuracy assessment was carried out at test site of Tikamgarh District, Madhya Pradesh for all the available and simulated data using common red and nir band covering 23 m (LISS-III), 36 m (LISS-II), 46 m (LIS-III Simul), 72 m (LISS-I), 92 m (LISS-III Simul), 144 m (LISS-I Simul), 184 (LISS-III Simul) and 188 m (WiFS) spatial resolution. The overall accuracy and kappa coefficient were computed for each data set, which were classified using maximum likelihood approach.

B. Sensor Radiometry

Radiometric resolution represents the ability of sensor system to detect a noise equivalent change in target spectral reflectance (NE$\Delta\rho$). It is also decided by number of quantization levels in which data is recorded. Radiometric requirement was evaluated theoretically against the ability of sensor to estimate the accurate crop

Normalized Difference Vegetation Index (NDVI) based on field-measured reflectance. Precision of crop NDVI measured from any sensor depends NE$\Delta\rho$ which is

$$NE\Delta\rho = \pi\, \Delta L\, d^2 / Eo \, Cos\theta$$

where ΔL is change in radiance equivalent to change in 1 bit of digital number and Eo solar extraterrestrial bandpass irradiance , θ being solar zenith angle and d is sun to earth distance in Astronomical Unit. Maximum error in computed crop NDVI [8] is

$$\Delta NDVI = NE\Delta\rho / (\rho n + \rho r)$$

where ρn and ρr are nir and red band crop reflectance. Precision in NDVI of both wheat and gram were calculated at different $NE\Delta\rho$ *by* above equation using field measured reflectance values. Attempt was also made to simulate different coarser radiometric data ie 4 bit, 6 bit, 8, bit, 10 bit and 12 bit from high radiometry 16 bit MOS-B data and study its influence on crop separability and classification accuracy. Sixteen wheat classes with high spectral overlap were evaluated in terms of their mean Transformed Divergence and Kappa coefficient at different simulated radiometric resolution.

C. Temporal Resolution

Temporal resolution is related to ability of sensor to acquire data at desired crop growth stage such as peak vegetative stage (PVS) for single date yield modeling approach. District NDVI estimated at time other than PVS causes error in yield estimation. Temporal resolution requirement was linked to noise equivalent shift from peak (NEΔtp), which is decided by the sensitivity of spectral crop yield prediction model. Temporal growth of crop in terms of NDVI [9,10] is given by

$$NDVI(t) = NDVIo\,(t/to)^{\alpha}\ \exp(-\beta\,(t^2 - to^2)) \quad for\ t > to$$

$$= NDVIo \quad for\ t \le to$$

Growth profile parameters ($NDVIo, to, \alpha, \beta$) including date of peak growth (tp) were estimated for 12 districts of central M.P. using 10 day MVC of NOAA-AVHRR global data.

IV. RESULTS

Inferences drawn along with suggestion for optimal sensor parameter for each resolution is discussed below.

A. Spatial Resolution

Field Sizes: Few studies on median contiguous field sizes in different locations in India have indicated 1, 3 and 20 hectares (ha) representing 20 %, 40 % and 80 % wheat proportion of agricultural area [11]. Maximum number of pixels, which can be accommodated in a field, was computed for 4 representative cases (1, 3, 5 and 10 ha) and assuming only 0.5 pixel border effect (case I) and additional geometric error effect of 0.25 pixels to account for multi-date registration, etc (Case II, Fig. 1). Assuming 3 ha to be the minimum patch to be studied, Case I will have 1 and 10 pixels for spatial resolution of 85m and 42m, while for Case II, 1 and 10 pixels would be available with spatial resolution of 70m and 37m. This suggests a spatial resolution better than 70 m for analysis of multi-date data sets of 3 ha. Multi-date monitoring in only contiguous field sizes is being addressed. While for full inventory, with individual fields being resolved or in case of multiple crops in a region, high spatial resolution data would be necessary.

Local variance: Wheat crop dominated areas showed a maximum variance (fig. 2) be-

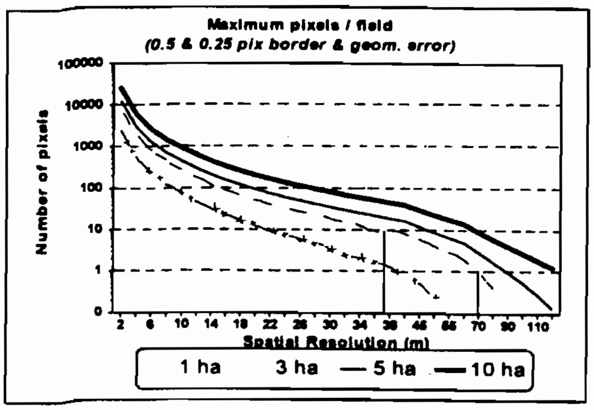

Fig. 1. *Maximum number of pixels which can be located in different field sizes when imaged at various spatial resolution.*

tween 46m and 92m suggesting the optimal resolution in that range. Scattered wheat areas showed maximum variance at 23m themselves indicating a need to investigate at better resolutions. The plantation areas showed a maximum at 184m while wastelands/ fallow land showed almost constant local variance at all resolutions.

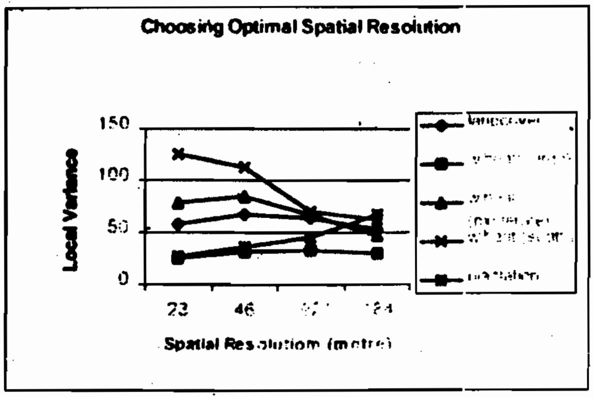

Fig. 2. *Selection of optimal spatial resolution based on maximization of local variance for different land cover classes using IRS-LISS-III data simulated at different spatial resolution.*

Classification accuracy: It was observed from Tikamgarh test site that there is considerable improvement in classification accuracy because of reduction in boundary pixels from WiFS to LISS-I spatial resolution. But the rate of increment of accuracy with increasing resolution above LISS-I level is relatively flat due to balance between relative reduction of proportion of boundary pixels with the increase of spectral variability (fig. 3)[12]. It also suggests that for large area single crop inventory, resolution around 70 meter with high repetivity is sufficient.

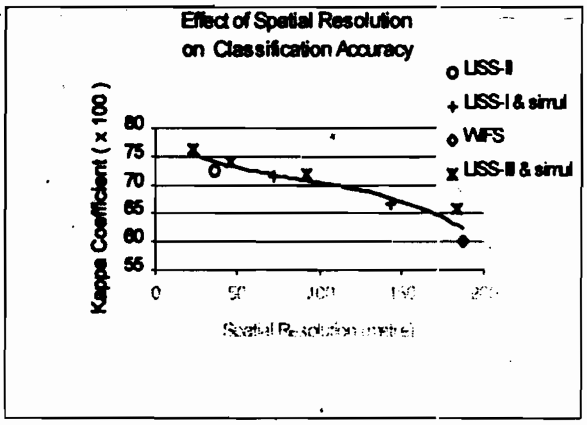

Fig. 3. *Classification accuracy assessment at different spatial resolution carried out using IRS – LISS-I, LISS-II, LISS-III, WiFS data.*

B. Radiometric Resolution

NDVI precision for the representative wheat reflectance (red .5% and nir, 53 %) observed from field measurement was computed. It was found that NDVI precision can be as good as 0.5% for NEΔρ of 0.25% (proposed LISS –IV sensor) to as poor as 4.166% for NEΔρ =2% (Landsat MSS, 6bit sensor). It was also observed that NDVI precision of gram crop is poorer as compared to wheat crop . For the precision of better than 1 % which is crucial for yield prediction models, NE$\Delta\rho$ < 0.3 % is suggested.

Increasing trend in Average Transformed Divergence (T.D.) distance for wheat classes was observed with increase in number of quantization. It improved from 1.27 at 4 bit to 1.42 at 6 bit and then reaches to 1.46 at 8 bit. Similar observations were found in terms of classification represented by kappa coefficient. Kappa coefficient at 4 bit was 0.35 which improved to 0.39 at 6 bit and reaches 0.41 at 8 bit. There was saturating effect after the 8 bits which could be because MOS-B sensor is primarily designed for Ocean application. For covering the all land cover feature, higher saturation radiance with 10 bit quantization is suggested.

C. Temporal Resolution

As repitivity of satellite becomes poorer the maximum temporal uncertainty to acquire data at peak stage increases so is the error in NDVI. A shift of one weak from peak introduce error in NDVI as much as 0.7%, which reaches to 2.1% for uncertainty of 12 days [13]. If error in NDVI at peak is to be restricted less than 1%, noise equivalent shift from peak (NEΔtp) has to be less than a week. If in hypothetical case peak of crop is fixed then the temporal revisit requirement is twice of NEΔtp. But in practical situations where there is spread in crop calendar by more than 15 days in India the revisit requirement is less than or equal to NEΔtp. Although when the crop has to be monitored either during cloudy kharif season or the foggy rabi season, the temporal resolution requirements become more stringent. It is suggested to have temporal resolution better than a week.

V. CONCLUSION

Sensor parameters such as spatial resolution, sensor radiometry, temporal resolution were studied to satisfy the need for frequent regional crop monitoring. For crop discrimination and mapping of 2-3 ha field sizes, it was observed spatial resolution of better than 70 meter would be needed. Radiometric resolution was also found important for crop separability, classification and crop biophysical parameter related indices. Precision in determination of NDVI was improved linearly with increase in radiometric resolution. For the precision of better than 1 % which is crucial for yield prediction models, NE$\Delta\rho$ < 0.3 % is suggested. It was also suggested that temporal resolution of better than a week is needed for restricting the NDVI error less than 1% due to acquisition date shift. Although requirement of spectral channels was not reported exclusively in this paper but based on experience [14], it is suggested that a minimal set of 4 bands would be needed. Red, nir & middle infra red (mir) bands are needed for discrimination & Vegetation Index (VI) computation. Green band for generating standard False Color Composite (FCC) should also be included.

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REFERENCES

[1] Baldev Sahai , "Agriculture resource inventory and survey experiment (ARISE)", ISRO Scientific Report. ISRO/SAC/TR/01/76, Space Applications Centre, Ahmedabad, 1976.

[2] George Joseph, "Imaging Sensors for Remote Sensing", Remote Sensing Reviews, vol. 13, 257-342, 1996.

[3] J.R.G. Townshend, "Selècting the spatial resolution of satellite sensors required for global monitoring of land transformation", Int. Jr. of Rem. Sen., vol 9, 187-236, 1988.

[4] D. L Toll, "An evaluation of simulated thematic mapper data and Landsat MSS data for discriminating suburban and regional landuse and landcover", Photogrammetry Eng. and Rem. Sens., vol. 50, 1713-1728, 1984.

[5] S. Kalyanraman, "Remote Sensing Data from IRS Satellites- Past, Present and Future", Photonirvachak, Journal of Indian. Society of Remote. Sensing , vol. 27, no. 2, 59-69, 1999.

[6] R.P.Singh S.R.Oza and V.K. Dadhwal, "Observations on Temporal Red Shift of wheat from multi-date space borne MOS-B spectrometer data." Photonirvachak, Journal of Indian Soc. of Remote Sensing, vol. 26, no.1&2, 3 47-56, 1998.

[7] P.J. Curran and H.D. Williamson, "Selecting a spatial resolution for estimation of per-field green leaf area index", Int. J. Rem. Sen., Vol. 9, no.7, 1243-1250, 1988.

[8] M. Roderick ,R. Smith and S. Cridland, " The precision of NDVI derived for AVHRR observations", Rem. Sens. of Environ., vol. 56, 57-65, 1996.

[9] G. D. Badhwar, J. G. Carnes, and W. W. Austin, "Use of Landsat derived temporal profiles for corn-soybean feature extraction and classification". Rem. Sens. Environ. Vol. 12, no. 1, 57-79, 1982.

[10] G.D. Badhwar, "Crop emergence date determination from spectral data", Photogrammetric Engineering and Remote Sensing, vol. 46, 369-377, 1980.

[11] V.K. Dadhwal, "Estimation of field length, breadth and area distributions in Vijapur (Gujarat) using aerial photographs". Scientific Note. IRS-UP/SAC/CPF/SN/05/85, Space Applications Centre, Ahmedabad, 1985.

[12] R. P. Singh, V.K.Dadhwal, K.P.Singh and R.R. Navalgund, "Comparative Evaluation of Indian Remote Sensing Multi-Spectral Sensors data for Crop Classification", Geocarto International, (Submitted).

[13] R.P.Singh, V.K.Dadhwal, K.P.Singh and R.R.Navalgund, " Error analysis of single date NDVI based crop yield prediction." International Journal of Remote Sensing. (Submitted)

[14] V. K. Dadhwal, J. S. Parihar, T. T. Medhavy, D. S. Ruhal, S. D. Jarwal and A. P. Khera, "Comparative performance of thematic mapper middle-infrared bands in crop discrimination", International Journal of Remote Sensing, vol. 17, no. 9, 1727-1734. 1996.