Biophysical Parameters Retrieval of Major Tree Species Using Cartosat-1 data

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ABSTRACT

In the present study CARTOSAT-1 data has been evaluated for retrieval of biophysical parameters like tree height, crown diameter, canopy density and canopy gap, which are critical variables for estimation of stand volume, biomass and generation of site index (indicator of site quality of growing stock). Based on this, empirical relationship were established between Cartosat derived estimated height & crown diameter and ground measured parameters. Cartosat-1 launched on 5th may 2005 is the first Indian operational remote sensing satellite capable of providing in –orbit stereo images with 2.5 m nadir resolution and 27 km swath. This satellite carries two panchromatic cameras mounted on board to take pictures in two different angles so that stereo pairs are produced, using which the required digital elevation models (DEM), and Ortho images can be produced. Investigations have been carried out at a site located in Forest Research Institute Campus, Dehradun. The site has major dominating forest species growing in the country in different age plots such as *Pinus roxbhurghii*, *Pinus caribea*, *Tectona gradis*, *Shorea robusta*, T*erminalia sps.* and *Eucalyptus spps.* CARTOSAT- 1 panchromatic data was corrected for geometric distortion using various GPS points collected at different altitudinal location. Based on this, orthoimage and Digital Elevation Model (DEM) were derived which have been used for facilitating large-scale cartographic forest stock information /plot boundaries and retrieval of various biophysical parameters. Analysis using Gray Level Co-occurrence Matrix and image segregation was performed for separation of forest species, homogeneity of the forest stand classes, stratification and measurement of crown area, canopy gap and stand density. Field measurement for each forest species i.e. tree height, diameter at breast height (DBH), stand density, age, crown diameter and other relevant parameter were made from each stand/plot. Statistically high correlation coefficient ($r^2 = 0.81$) was found between DEM derived average tree stand height and actual measured tree stand height for all the forest species studied. Empirical models for prediction of DBH were developed and validated with Cartosat drived height and crown diameter. Measured and predicted values were found in close proximity to each other as is shown by the values of Pearson's coefficient. A local contrast co-occurrence measure (contrast, mean and variance) calculated for 3x3 and 5X5 pixel window has been found suitable for estimation of average crown diameter, stand density and canopy gap area for each forest stand class/plot. Texture image is found to be strongly related to structural attributes i.e. stand density, crown diameter and canopy gap of the forest tree stands. The results presented in this study show that CARTOSAT-1 stereo derived DEM and orthoimage have good potential for the estimation of stem volume, growing stock conditions, biomass and site index for important timber species in reasonable accuracy and cost effective manner.

1. INTRODUCTION

Retrieval of forest biophysical attributes information such as species composition, canopy density, canopy diameter, tree height and age from remotely sensed data are required by forest managers, planners and policy makers for estimation of volume, biomass and updation of forest growing stock condition of the country's forest. In the national and global level perspective such information is needed for understanding existing carbon stock in the systems, climate, climate modelling, biogeochemical cycling, and wildlife habitat modelling and fire management (Anonymous, 2004, Franklin et al., 2000). In the past, traditional methods of forest stock inventory involved detailed field surveys, which were found to time consuming, costly and lacked uniformity and accuracy.

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In recent years, availability of new generation high resolution satellites sensor data IKONOS (1m resolution), QuickBird (1 m resolution), Orbiew -1 (1, 2 and 4 m resolution), TES (1 m resolution) and Cartosat -1 (2.5 m resolution)), have opened up new era for making forest inventories and assessing forest biodiversity at landscape level (Carleer and Wolf, 2004). As result high-resolution satellite pixel observations from space have shifted from forest stands, clusters of trees or mixture of some land cover types to individual trees. This has facilitated in cutting down the inventory time and cost significantly. In forestry planning, the most important parameter is the stem volume measurement in the units of $m^3 ha^{-1}$ or average volume per ha in a stand and above ground respectively which are related to commonly used parameters in climate studies, biomass, measured in tons ha^{-1}.

Studies have demonstrated that satellite remote sensing data can be related to a number of forest stand level parameters and that these relationships can aid in the process of forest inventories (Muukkonen and Heiskanen, 2005, Wulder and Seeman, 2003, Franklin and McDermid, 1993). In the optical portion of the spectrum, these relationships are largely a function of canopy structure and the physical interaction between radiation and vegetation amount, but is constrained by the inability to make physical measurement of the vertical structure (height) of the forest canopies in three-dimensional (3D) forms (Wulder, M., 1998A).

In the present study Cartosat-1 data has been evaluated for retrieval of forest biophysical parameters (height, crown diameter, canopy density and hence diameter at breast height, DBH and establish empirical relationship between Cartosat stereo data measured biophysical parameters and ground based tree parameters. This study has been carried out in experimental plots of Forest Research Institute estate Dehradun, Uttaranchal. The site consist of major dominating tree species growing in the country in different age plots such as *Pinus roxbhurghii*, *Pinus caribea*, *tctona grandis*, *Shorea robusta*, *Ttermenalia* sps. and *Eucalyptus* spps.

1.1 Retrieval of forest biophysical parameters

Measurement of forest stand tree heights, canopy cover, crown size, stand density, and tree Diameter at breast Height (DBH) are a must for the assessment of forest volume, biomass and growing stock of the forest area. These parameters are highly correlated, and influence the reflectance properties of the canopies (Anonymous, 2004). In the past, estimates of tree height and crown diameter of dominant and co-dominant forest tree species were derived based on photogrammetric principle using parallax measurements of aerial photographs and rigorous ground sampling inventory. Thus stand volume tables were derived by multiple regressions analysis that can be used to analyze the relationship between the dependent variable and one or more independent variables (s) measured on photographs or by traditional field surveys (Maslekar, 1974). Forest measurements on photographs covering large areas can become a tedious endeavor and to some degree rely on the interpreter's ability. Since it is generally not feasible to measure and count every tree in the area of interest, a sampling process analogous to field procedures is often used.

The image spatial structure is only a two dimensional representation of forest structure. Improved two dimensional high resolution satellite images (2D) have provided structural characteristics of the forests on ground, but do not give the information on the third dimension, height of the forest trees, which are essential for forest inventories and various forest operations. Thus three-dimensional (3D) information in digital form with good resolution in planimetry and height direction becomes essential for retrieval of forest stand tree height, crown diameter and other topographical features.

In this context, Cartosat – 1 high-resolution (2.5 m resolution) panchromatic stereo data, could generate image in three dimensional domains through Digital Elevation Model (DEM) , which will able to retrieve vertical dimension of the tree height.

1.3 Cartosat-1

Cartosat-1 launched on 5th may 2005 into a 618 km circular polar sun synchronous (10.30 AM local time) orbit is the first Indian operational remote sensing satellite capable of providing in –orbit stereo images with 2.5 m nadir resolution and 27 km swath. This satellite carries two panchromatic cameras to take pictures in two different angles i.e. Fore camera collect the image angles at +26 degree with respect to nadir in the direction of transit and other Aft camera angle at -5 deg. with respect to nadir trailing the satellite's local vertical. These two cameras provide stereoscopic image pairs in the same pass. Through these stereo- pairs digital elevation models (DEM), and ortho images of the area can be produced (Kirankumar, and Kurian, 2005). Important specifications of cartosat-1 are summarized in table-1.

Table 1 Major Specification of Cartosat-1 satellite

Sensor	PAN 2 Camera (Fore and Aft)
Spectral Bands μm)	0.5 – 0.85
Ground Resolution (m)	2.5
Swath (Km)	30 (Fore) 27 (Aft)

B/H	0.6
Stereo Set	Pair Fore (+ 26 deg.) Aft (-5 deg)
Quantization	1024
SNR	> 400
Data Compression	3.3:1
MTF	25

2. OBJECTIVES

- The objectives of this study are to investigate the use of Cartosat-1 data for retrieval of forest biophysical parameters like stand density, canopy gap, tree height and crown diameter
- To develop empirical model for prediction of DBH from Cartosat derived height and crown diameter
- To establish empirical relationship between Cartosat stereo data measured biophysical parameters and ground based tree parameters

3. STUDY AREA

The study was carried out in experimental plots of Forest Research Institute estate Dehradun, Uttaranchal (lat.33^0 25'-33^0 40' and long. 78^0 25'-78^0 40'). The lush green estate spread over 450 ha, with the outer Himalayas forming its backdrop. The topography of the area is of gentle relief, with elevation ranging from 584 to 617 m above sea level (Figure 1). The area is typical representative of country's major forest species i. e. Sal (*Shorea robusta*), Teak (T*ectona grandis)* Chir pine *(Pinus roxbhughii),* tropical Pine (*Pinus caribaea*), Michellia champaca, Syzigium cumini, Termenalia *tomentosa*,, Eucalyptus species and Bamboo etc. Average forest stands age of this area is dates back to approximately 1925 to 1927. The climate is subtropical and humid.

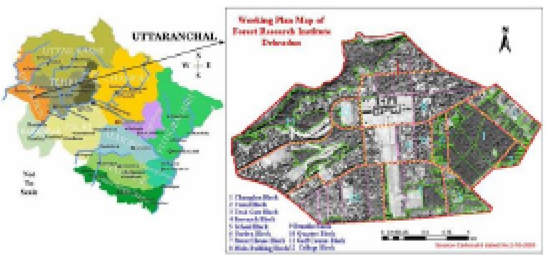

Figure 1 Study area

4. DATA USED AND METHODOLOGY

4.1 Field data collection

Field data inventories have been collected from experimental homogenous forest tree stands/plots (7 species) in FRI Estate, Dehradun during the months of January 2006 (Table 2). Identification of sample plots location was done using Cartosat-I image generated maps at 1:12,500 scale and FRI Working plan maps. A total of seven plots, each around 1ha in area, were used to collect forest biophysical parameters .Figure 1 depicts the different forest species plots and their boundaries. All field parameters were measured on a quadrate basis with quadrate covering and area of 5 m x5 m. This yielded 10 m wide transects, providing a compatible width for field measurements to be related to Cartosat imagery with a pixel size of 2.5 m x 2. 5 m. Differential Global Positioning System (DGPS) were used to determine the location of the center of each plot. Within each plot, the species, DBH, tree height and crown diameter were recorded for each tree species. Diameter of all trees on each plot was measured at breast height, i.e. 1.37 m above ground surface. Height related measurements were made using a vertex hypsometer. Crown diameter was estimated using a tape measure along the major and minor axes. Crown closure was calculated as the ratio of the sum of the surface area of the crown of each individual tree in a plot divided by the area of the plot. The stands age of these experimental plots varies from 35 to 75 years. Based on field data collection, following biophysical forest matrices attributes as shown in table 2 and 3 were derived.

Table 2 Showing different forest species and plots

Forest cover/Tree species	No. of Plots	Extent of area (ha)
Pinus roxbhurghii	5	8
Pinus caribaea	3	3
Pinus Sps. (young plant)		2
Shorea robusta	3	3
Tectona grandis	2	2
Termenalia Sps.	1	1
Eucalyptus Sps.	2	3

Table 3: Statistics of biophysical parameters (height, crown width and DBH) measured From field inventory

Statistics	DBH (cm)	Height (m)	Crown width (m)	No. of tree/plot
Chir Pine				
mean	51.06	24.00	11.77	10 /5
min	33.70	17.50	7.30	
Max	65.20	29.50	14.80	

SD	11.35	3.86	2.31	
Tropical Pine				
mean	37.00	22.30	8.01	10/3
min	29.80	19.50	6.20	
Max	44.70	25.50	10.60	
SD	5.32	2.14	1.38	
Teak				
mean	44.92	23.62	9.00	8/3
min	29.8	19.50	6.40	
Max	59.30	26.50	11.20	
SD	12.47	2.16	1.63	
Sal				
mean	35.17	22.94	6.87	9/2
min	20.80	16.50	4.60	
Max	63.00	27.50	9.80	
SD	12.57	4.03	1.67	
Terminal ia				
mean	29.83	31.00	4.6	6/1
min	17.20	19.50	3.5	
Max	41.40	37.50	5.8	
SD	9.65	8.21	0.8	
Eucalypt us				
mean	30.64	19.72	6.87	9/2
min	21.00	16.50	4.60	
Max	38.90	22.50	9.80	
SD	6.70	1.92	1.67	

4.2 Satellite Data used

Cloud free Cartosat -1 image acquired over the study area on November, 2005 was used for detailed analysis. The Solar elevation and solar azimuth at the time of data acquisition was

4.3 Ancillary Data

- Survey of India topographical maps
- FRI Working plan maps
- DGPS Surveys points
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4.4 CARTOSAT DATA ANALYSIS

4.4.1 Extraction of DEM and Orthoimage

PCI Geomatica version 8.2, ERDAS Imagine and ENVI were the main software packages used for processing of Cartosat-1 data. Cartosat-1 panchromatic data was corrected for geometric distortion using Differential Global Positioning System PS (DGPS) points taken from different altitudinal location in forested and non-forested area. All these DGPS points were identified on the Fore and Aft stereo images. The registration of image was performed using nearest neighborhood re-sampling algorithms with first order polynomials. Based on this, orthoimage and Digital Elevation Model (DEM) were derived which have been used for facilitating large-scale cartographic forest stock information /plot boundaries and retrieval of various biophysical parameters (Figure 2). Automated image correlation algorithms were used to derive elevation from the parallax, by a set of well located GCPs and tie points (TPs). The image matching technique operates on a reference and a search window and for each position in search window a match value is compared from gray level values in the reference window. The match value is computed with mean normalized correlation coefficient and the sum of the mean normalized absolute difference elevation points are extracted at every pixel. The 3-D intersection is performed using the computed geometric model to convert the pixel coordinate in both images determined in the image matching of the stereo pair to the three dimensional data. The height accuracy of the extracted DEM has been compared with their corresponding reference DEM and ground DGPS points take from forested and non-forested area.

4.4.2 Textural Analysis

Image texture is a measure of the spatial frequency of tonal change within a set distance on an image (Jensen 1996). Therefore, to derive the level of textural spatial information variation between high resolution Cartosat- 1 image pixels and its neighbors for separation of forest species, homogeneity of forest stand, stratification and measurement of crown area, canopy gap and stand density. Gray –level Co-Occurrence Matrix (GLCM) statistical measures was used for textural analysis of cartosat-1 data. Based on this six textural measures were generated. These six co-occurrence texture algorithms measure i.e. mean, contrast, variance, dissimilarity, entropy and homogeneity based on co-occurrence matrix that calculates the relative frequencies with which pixels values occur in two neighboring processing windows i.e.3x3 and 5x5 pixels (figure2)

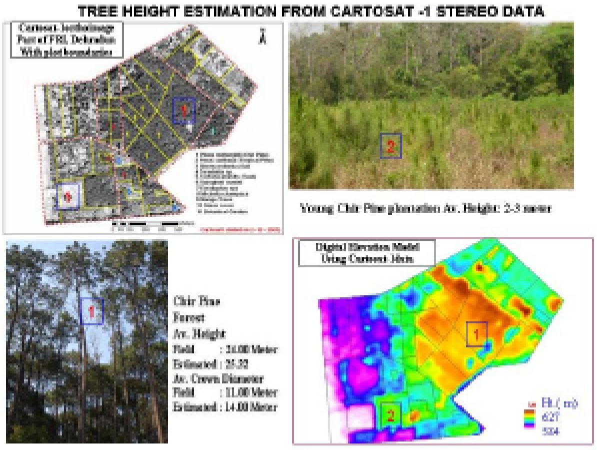

Figure .2 Extraction of Orthoimage and DEM retrieval of tree height and crown diameter. [1] Chir Pine (*Pinus roxbhurghii*) , [2] young plantation of tropical Pine (*Pinus carebea*) shown on field and Cartosat-1 (ortho & DEM) image.

4.4.3 Retrieval of tree height and crown diameter

Individual tree stands of the *Pinus roxbhurghii*, *Pinus carebea, Pinus sps. (Young plant), Shorea robusta*, *Tectona, grandis, Termenalia sps. and Eucalyptus species* were identified correctly on 5 x 5 pixels window in each sample plots on orthoimage and 3 x 3 pixel window texture generated image (fig. 2 and 3). Stand tree height for each species was measured from sample plots (5 x 5 windows size) from individual trees and adjacent canopy gap area or forest-cleared area using stereo image and stereo derived DEM. When the forest clearing was perceived to be horizontal, tree height was computed from the difference of the means between all elevation stereo measurement outside and inside the clearing, respectively. To determine the crown diameter of the same trees / stand polygons were traced manually around the tree crowns. Height and crown size of the individual trees species/stand was then regressed against field measured tree height, DBH and crown diameter.

5. RESULTS AND DISCUSSION

In the present study, availability of high spatial textural information and thee dimensional (3-D) vertical height measurements from Cartosat – 1 stereo data with strong geometrical and planimetric fidelity has made possible the retrieval of forest biophysical parameters like forest stand density, tree height, and crown cover/diameter and canopy gap area. Cartosat-1 derived retrieved in formation have been validated with ground measured data and have shown high degree of correlation.

Table 4 Statistics of Retrieval of biophysical parameters (Height and Crown width) measured from Cartosat-1 Stereo data

Statistics	Height (m)	Crown width (m)	No. of tree/plot
Chir Pine			10/5
mean	25.32	14.0	
min	22.1	9.0	
Max	30.01	18.0	
SD	2.57	3.05	
Tropical Pine			
mean	23.62	8.76	7/3
min	20.0	7.0	
Max	27.99	11.0	
SD	2.77	1.22	
Teak			
mean	24.26	9.6	8/3
min	21.0	7.0	
Max	27.01	12.0	
SD	1.90	1.71	
Sal			
mean	22.91	6.80	7/2
min	16.00	4.60	
Max	28.0	9.80	
SD	4.69	1.67	
Terminalia			
mean	32.6	5.23	5/1
min	21.0	4.0	
Max	38.0	6.7	
SD	6.8	0.87	
Eucalyptus			
mean	20.04	7.64	7/2
min	17.0	6.00	
Max	23.50	10.00	
SD	2.19	1.57	

5.1 Relationship of high spatial resolution textural information with forest stand attributes

Spatial textural information obtained from high resolution airborne and satellite platform has been considered potentially important information source for forestry purposes (Anonymous, 2004). Quantifying spatial information of high-resolution data is more difficult than the spectral information as it involves measurement of variability, pattern, shape and size. Texture properties in the image have always been a primary visual cue for defining areas and relate to the visual perception of coarseness or smoothness of image features ((Lillesand and Kiefer., 2000). Among the six textural co-occurrence measures, contrast, mean and variance calculated from 3 x 3 pixel window have been found suitable for estimation of stand density, crown diameter and canopy gap area for each forest stand class/plot. These measures yielded the highest mean (ranges from 2.72 to 13.75) and standard deviation (11.17 to 25.01) value (using a window size of 3X 3 pixels) and indicate positive correlation with forest attributes and other measures which have shown low correlation with forest structural attributes (table 4 and figure 3).

Table 5 Statistics of Co-occurrence textural measures calculated from 3 x 3 window pixel

Co-occurrence textural measures	Mean	Stand. Dev
Mean	13.75	11.17
Variance	2.72	13.28
Contrast	5.77	25.01
Homogeneity	0.64	0.29
Dissimilarity	1.11	1.30
Entropy	1.17	0.94

Texture image (as shown in figure 3) has been found to be strongly related to structural attributes i.e. stand density, crown diameter and canopy gap of the forest tree stands. Mature forests of Chir Pine, Sal and teak were found to have high variation (variance = 5.0) while the younger plantations showed the least spatial variation (variance = 0.5). Collins and Wood cook., 1999., Franklin et al., 2001 have found that the image variance is related to information content in images and therefore, determines the ability to extract useful information about the image. The differences in the close canopy variance and contrast values suggested that that there were different degrees of spatial variability (texture) between the species.

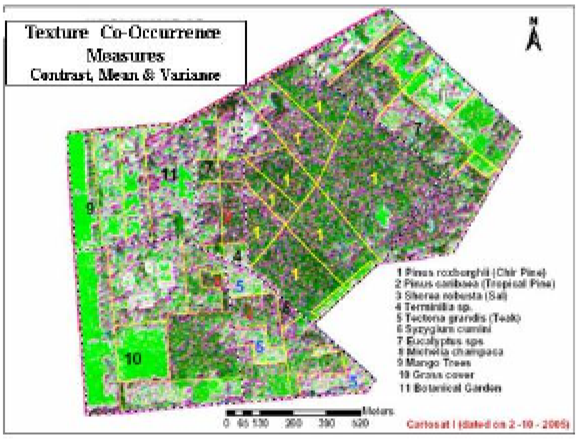

Figure 3. Texture Co-Occurrence measure (Contrast, mean and variance) calculated from 3x3 pixel window showing strong relationship with forest structural attributes

5.2 Relationship between Cartosat-stereo DEM retrieved biophysical parameters from and field measurements

Information on three-dimensional structures of the forests provides the best understanding into the stratification of canopy and tree height. Individual trees crowns were identified on Cartosat – 1 textural and stereo image on the basis of crown texture and three dimensional morphology. Plot wise statistical analysis (i.e. mean, minimum, maximum and Standard deviation) of individual species tree heights and crown diameter retrieved from Cartosat -1 stereo image and DEM and field measured inventory (height, crown diameter and DBH) have been presented in table 2 3 and figure 4 to 6. Good correlation has been e observed among the Cartosat-1 estimated and field measured parameters for all the six species studied. Empirical regression relationship was developed between the Cartosat-1 retrieved tree height and crown diameter and field measured inventory. Mean measured tree height was plotted against the height estimates obtained from Cartosat data for different tree species as shown in figure 4a & 4b, clearly describe a significant correlation (r^2 =0.9). Similar positive trend (figure 5a & 5 b) were obtained for measured and estimated crown diameter for different species (r^2 =>0.9).

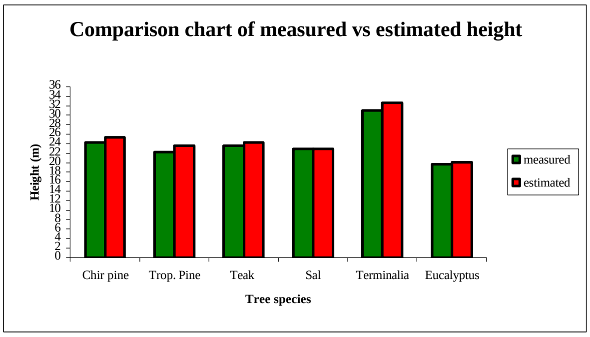

Figure 4a: Comparison chart showing measured and estimated height

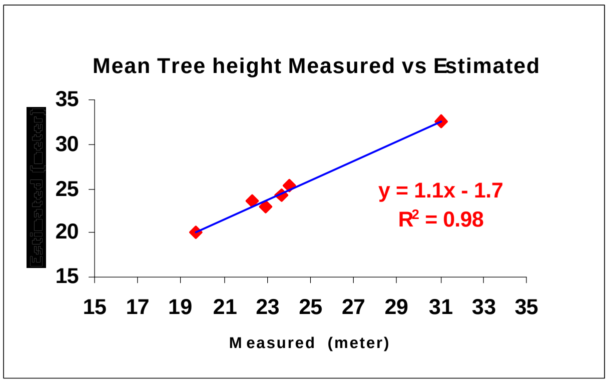

Figure 4b. Regression plot showing measured and estimated height

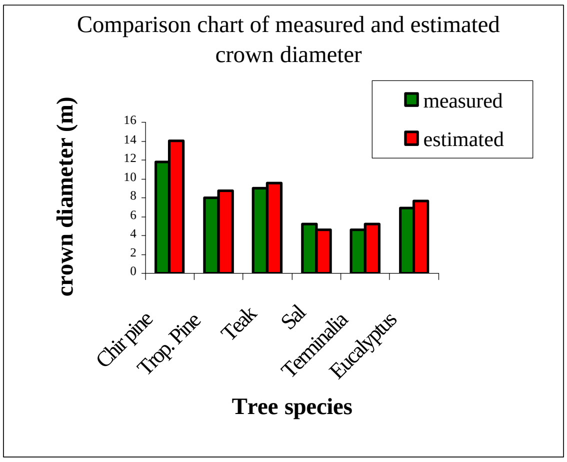

Figure 5a. Comparison chart showing of measured and estimated crown diameter

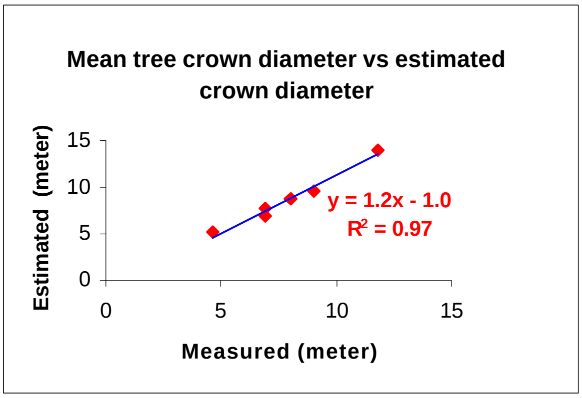

Figure 5b. Regression plot showing of measured and estimated crown diameter

Retrieval of the tree height and crown diameter from high resolution Cartosat -1 image have been found to be related to growth stage, DBH, basal area, volume and above ground biomass of the forests. The most important tree variables generally used in tree volume estimation and growing stock updation in India are DBH and tree Height (Anonymous, 1996). As reflected in figures and tables high variation and coarse texture of the image indicate maximum height and DBH (Chir Pine) as compared to low texture variation (Young 2-3 meter Pine plantations). DBH and Height were significantly correlated. Therefore, empirical models for prediction of DBH for different tree species using measured and estimated tree height, crown diameter and DBH were computed. The models developed for DBH were used for predicting Cartosat-1 DBH and height derived using the same datasets. Measured and predicted values are in close proximity to each other as is shown by the values of Pearson's coefficient (figure 6a and 6b). Further, DBH was plotted against tree height and crown diameter respectively and straight-line graphs were obtained depicting the linear dependence of DBH over tree height and crown diameter. As a result, regression analysis was performed to obtain the best possible empirical relationship between the three biophysical variables.

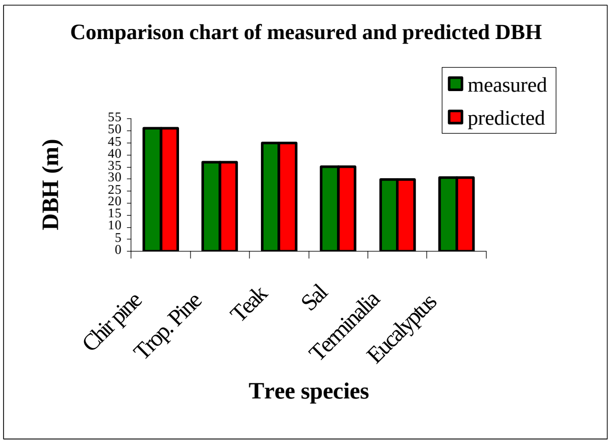

Figure 6a. Comparison chart showing of measured and predicted DBH

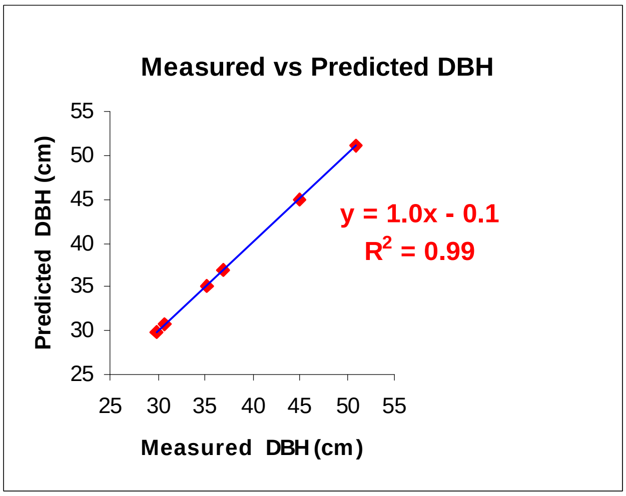

Figure 6b Regression plot showing of measured and predicted DBH

6. CONCLUSIONS

- The study has demonstrated that Cartosat-1 extracted high spatial textural information and three dimensional vertical height measurements from stereo data vis-a vis strong geometrical and planimetric fidelity of the data have been found potentially useful for retrieval of forest biophysical parameters like forest stand density, tree height, and crown cover/diameter and canopy gap area.

- Significant statistical correlations (r^2 =>0.90) were found between Cartosat estimated height and crown diameter, and field measured data. Empirical models for prediction of DBH have been developed and validated with Cartosat derived estimates. Good correlations have been are observed between predicted DBH and measured DBH.

- Retrieval of such important biophysical information from Cartosat-1 stereo derived DEM have potential for estimation of forest biomass, stand volume, growing stock condition and generation of site index for important timber species with reasonable accuracy, time and cost effective manner.

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