ESTIMATION OF FOREST BIOMASS FROM ESTAR IMAGE DATA

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ABSTRACT:

Image data from L-band airborne radiometer measurements over conifer forest stands in southern Virginia USA have shown a strong sensitivity to biomass and a weaker sensitivity to soil moisture. The data, was obtained by the horizontally polarized synthetic aperture radiometer, ESTAR, deployed aboard a NASA P3 aircraft. The data was acquired in July, August and November of 1999. The imaged region, which is owned by International Paper Company, consists of even aged loblolly pine stands of approximately one to two kilometers on a side. The stands range in biomass from 20 to 200 tons/hectare and are located on mostly flat ground.

To understand the dependence of brightness temperature on biomass and soil moisture, a passive discrete scatterer model of the forest has been employed. Soil moisture and tree geometry measurements, made at the time of the over-flights, provide input data for the forest model. The model results agree with the measurements to within experimental error. The results of the measurements and the modeling indicate that L-band brightness temperature is sensitive to forest biomass. However, for stands of smaller biomass, the emission from the ground has an increasing role.

1. INTRODUCTION

In 1999 ESTAR, an L-band radiometer was flown over conifer forest sites located near Waverly, Virginia USA. The forest stands, which were owned by the International Paper Company, were of various ages. The purpose of the flights was to determine the effect of varying biomass and soil moisture conditions on the response of the L-band radiometer.

The retrieval of forest biomass from space has been the subject of investigation for over a decade. Investigators have found that L-band (1.413 GHz) is a good compromise between the ability to penetrate canopies and drawbacks such as antenna size and the effects of the ionosphere. Radar backscatter at L-band has been shown to be sensitive to the level of biomass however, the signal saturates rapidly as the biomass increases (Dobson et al, 1992, Ranson & Sun, 1994 and Imhoff, 1995). Ferrazzoli and Guerriero (1996) have made a model investigation of the sensitivity of brightness temperature to variations in biomass. Their calculations indicated that passive sensing at L-band is more sensitive to biomass than active sensing techniques. Lang et al (2000), Macelloni et al (2001) and Lang et al (2001) reported on passive L-band measurements of biomass which demonstrated their increased sensitivity to biomass.

In the present paper the modeling work that was done to verify the passive measurements at the Waverly site in Virginia will be discussed. Of the many stands that were imaged by the ESTAR radiometer, two were chosen for careful study. Their forest statistics and ground moisture have been measured. This data will be used in a passive model to estimate the brightness temperature. The effects of biomass and soil moisture will be examined by using the model.

2. DESCRIPTION OF EXPERIMENT

ESTAR is an L-band radiometer, which uses a real aperture to obtain resolution along track and a synthetic aperture to obtain resolution in the cross track direction (Le Vine, 1999). The radiometer operates at 1.413 GHz and is horizontally polarized. The instrument is mounted in the bomb-bay door of a P3 aircraft as shown in Figure 1. Four flights were made over the Waverly test site in 1999. Flights were made on July 7,

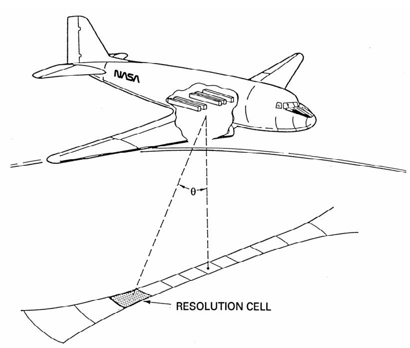

Figure 1. ESTAR radiometer on board P3 aircraft

August 27, November 15 and November 30. Moisture conditions and temperatures varied for each of the days. The P3 flew two flight paths in the form of a cross whose intersection overlapped a portion of the test sites. The plane flew at an altitude of 1.5 km (1500 ft) or 3.0 km (3000 ft) which resulted in swath widths of 1 km and 2 km respectively.

The Waverly site is owned by the International Paper Company and consists of plantation stands of loblolly pine growing on mostly flat ground. The stands range in age from 2 to 30 years old with some selected stands being even older. The stands were typically 1 to 2 km on a side; large enough to contain several ESTAR resolution cells. Six stands were chosen for detailed investigation. To help show the location and extent of each stand, a Landsat image of the region is presented in Figure 2 with the stands 1-6 labeled on the image.

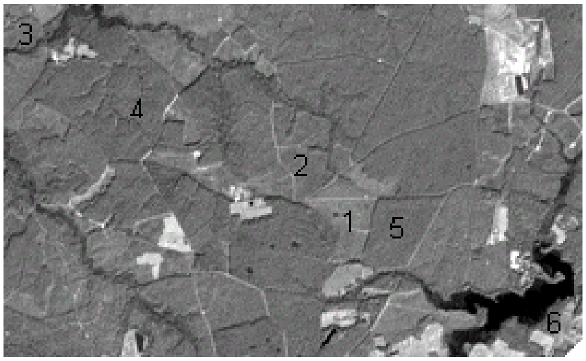

Figure 2. Landsat image of Waverly site

The numbers also correspond to the ages of the trees - larger numbers indicating older trees. The dark area in the image between sites 5 and 6 is Airfield Pond. The very light regions are clear cuts while the regions that are a little darker than the clear cuts are regions of newly planted trees. Site 1 consists of trees that are 2 years old at the time of the experiment. A picture showing the small trees in site 1 and the 18 year old trees in site 5 is shown in Figure 3. The boundaries of the sites can be seen in the Landsat image. The difference between site 1 and 5 is clear, however it is difficult to see the difference between trees in sites 2 through 6 because the canopies are dense and mask the ground.

Figure 3. Two-year-old trees of site 1 with 18-year-old trees of site 5 in the background.

3. ESTAR DATA

The ESTAR data will be examined from two different perspectives: spatial and temporal. In the spatial case, the biomass of different stands will be compared to their brightness temperatures. In the second case, two stands will be examined as a function of time to see how their brightness temperatures vary with changes in soil moisture.

In Figure 4 an image generated from the ESTAR flight of November 15 is shown. The sites have been numbered as above using the same convention as shown in the Landsat image. Also, the local road system has been superimposed on the image. The colors correspond to brightness temperatures whose scale is shown on the right hand side of the figure. Airfield Pond is clearly visible on the image although not in the same detail as in the Landsat image. The difference between the 2 years trees of site 1 and the 18-year-old trees of site 5 is clearly visible.

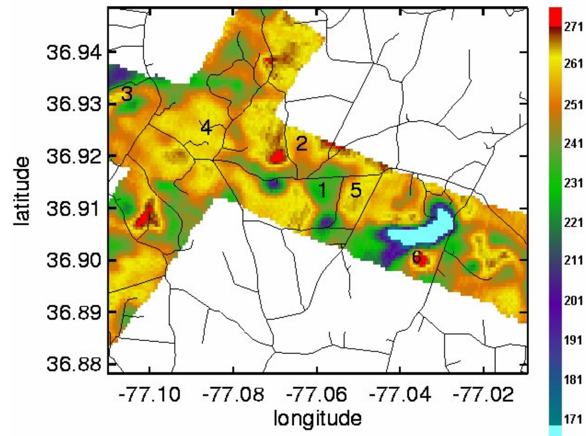

Figure 4. ESTAR brightness temperature maps for flights on November. 15, 1999

International Paper Company has supplied us with the biomass of trunks for site 1 through 5. Twenty percent was added to account for branches and needles to obtain the total biomass of each site. The biomass in tons/hectare is plotted in Figure 5 versus the brightness temperature in degrees Kelvin from the November 15, 1999 flight. The sixth site, which is privately owned, consists of huge trees, which are most likely over seventy years old. Their biomass has been determined from basal area estimates and represents the highest point on the curve. A regression curve obtained by using a least squares fit is also shown in Figure 5. Considering that the radiometer has a resolution on the order of 1^{o}K, one is able to predict the biomass from the brightness temperature with a good degree of accuracy.

An important issue from the perspective of monitoring biomass is the effect of changes in soil moisture on the brightness temperature. The flights took place over a period of five months, during which a variety of different moisture conditions have been encountered. providing data to address this question.

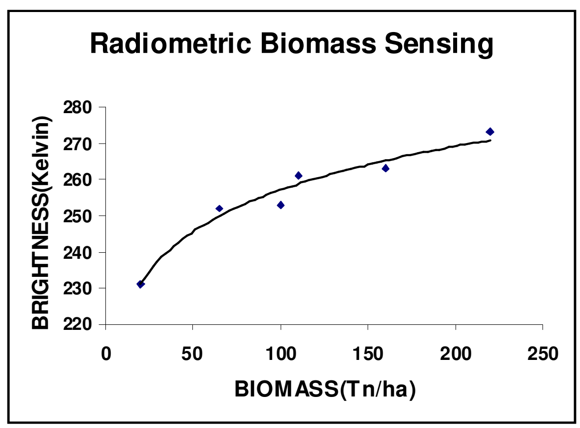

Figure 5. Brightness temperature vs. biomass

To study these effects of soil moisture, closer attention has been concentrated on site 1 and site 5. which will be called the Airfield Pond Regeneration (APR) site and the Airfield Pond Mature (APM) site, respectively. Soil moisture values have been recorded at these two sites for each of the four over-flights and measurements have been made of tree architecture. The brightness temperatures over these sites are shown in Table 1 along with the physical temperature at each site. The physical temperatures were obtained from the Wakefield weather station which is about 40 km away from the Waverly site.

	July 7	Aug 27	Nov 15	Nov 30
APR	265.5	252.0	233.0	235.0
APM	281.2	272.0	263.0	262.0
T^oK	302.4	299.1	286.3	278.6

Table 1. Brightness and physical temperature at each site.

An examination of the brightness temperatures in the table shows that there is approximately a 30°K change in brightness temperature at the APR site while there is a 20°K change in brightness temperature at the APM site. Much of this change is due to the fact that the physical temperature has changed, however the change is larger in the APR site, which has the small trees. This represents the influence of changes in soil moisture.

4. FOREST MODEL

The loblolly pine stands have been modeled using the Peak approach, which relates the active and the passive problems (Peake, 1959). Basically, the brightness temperature is written as the physical temperature times one minus the scattering albedo of the forest layer. The scattering albedo of the layer is then computed from the bistatic scattering coefficient. The passive problem has now been reduced to an active problem. The approach has been used before by Chauhan et al (1999) for forests, Chauhan et al (1994) for corn canopies, and by Saatchi et al (1994) for grass.

In the work to be presented here, the bistatic scattering coefficient of the forest is found by employing a discrete scatterer approach wherein the forest is considered to be a dielectric layer containing randomly distributed and oriented cylindrical scatterers. The trunks, branches and needles are modeled as finite length cylinders, which are given prescribed orientation statistics obtained from measurements in the forest as shown in Figure 6. The individual scattering cross section of each type of scatterer is used in the calculation. For more details see Chauhan et al (1991).

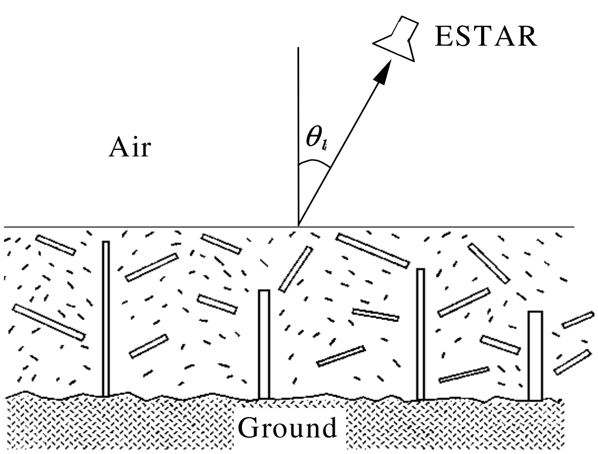

Figure 6. The forest model

5. GROUND TRUTH

Ground truth data was collected during and after the experiment. Soil moisture measurements were obtained at the time of the over-flights while forest stand parameters were estimated in February 2001. The forest floor had an organic layer of tree litter over a sandy loam soil. The litter layer varied in thickness from 0.5 to 5 cm across the forest floor. Samples were taken and divided into litter and soil parts. The thickness of the litter layer was also recorded. Separate measurements for average bulk density (g/cm^3) and gravimetric soil moisture, m_g (%) of both soil and litter were made. As a first approximation, the average of soil and litter were used to compute the bulk density and the gravimetric soil moisture. The average bulk density and the average gravimetric soil moisture were then used to determine the volumetric soil moisture, m_V , on each date. These estimated values of m_V for the APR and APM sites are given in Table 2. Estimates of surface roughness in terms of the rms height, σ , and correlation length, l , were also made but are not given here since the surface scattering effects were small.

	July 7	Aug. 27	Nov. 15	Nov. 30
APR	0.12	0.38	0.46	0.51
APM	0.27	0.33	0.39	0.42

Table 2. Estimated volumetric soil moisture, m_v , for APR and APM sites

The diameter at breast height (DBH), stem density and height of the stand were collected for the APR and APM sites. The size distribution of the trunks for both sites is given in Figures 7 and 8 for the APR and APM sites respectively. The branches were classified according to their base diameters and the average density of each type was estimated. Distributions similar to those presented in Figures 7 and 8 were obtained for the branches but are not shown here. These distributions were incorporated in the forest model to take into account variations in trunk and branch sizes. Average stem densities for APR and APM sites were 0.23 stems/m^2 and 0.19 stems/m^2 respectively. The needle dimensions and density were also measured. An

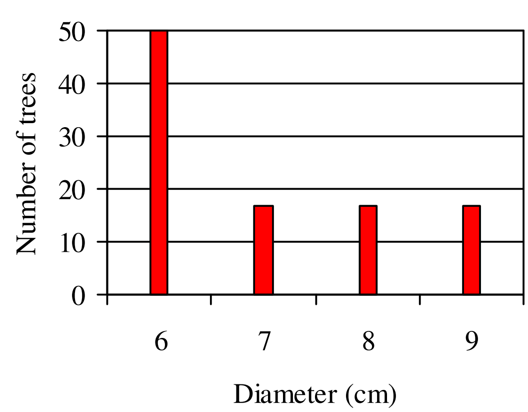

Figure 7. DBH distributions for APR site

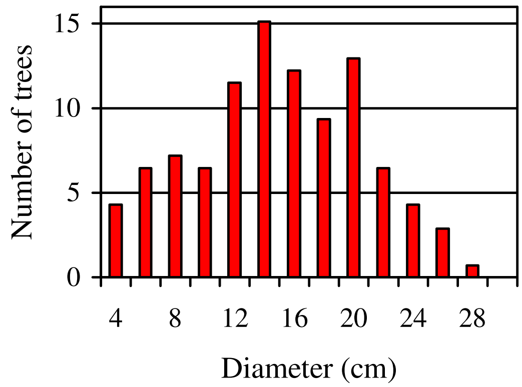

Figure 8. DBH distributions for APM site

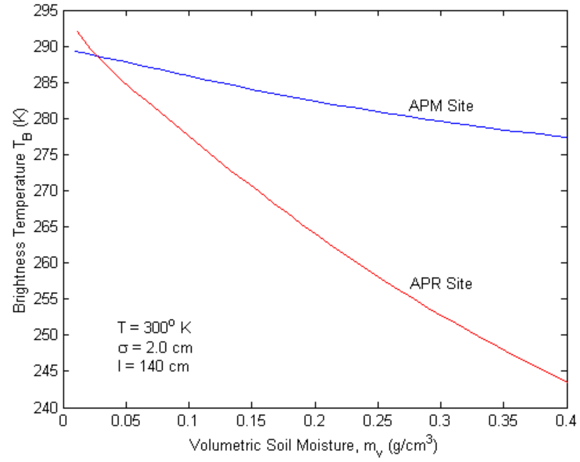

Figure 9. Model variation of brightness temperature with soil moisture for the APR and APM sites.

average needle size was used in the model. Furthermore - based on these measurements - the biomass of the APM stands was estimated to 160 tons/ha. Although this is close to the biomass, estimated by using the lumber company's empirical formula, this number must be reduced somewhat since it was made 18 months after the flights.

6. DATA ANALYSIS

The forest model has been used to reproduce the ESTAR data for the APR and APM sites. In order to understand the impact of soil moisture variations on the retrieval of forest biomass, model generated curves for brightness temperature versus volumetric soil moisture for both the APM and APR sites are plotted in Figure 9. In this plot a fixed physical temperature of $T = 300^o$ K has been assumed. As expected the model predicts that the brightness temperature decreases with increasing soil moisture This is due to the fact that the emissivity of ground decreases with increasing soil moisture. The curves also clearly indicate an increase in sensitivity to soil moisture with a decrease in foliage density. This is because the foliage becomes more transparent as its density decreases; hence, the effect of changes in ground emissivity due to soil moisture becomes more visible. The combination of these two effects results in higher sensitivity to biomass when soil is very wet (as is clearly visible in the figure). This occurs when there are wet conditions since the contribution of the ground is much less than from the vegetation canopy. In general, both the soil surface and the forest canopy (soil moisture and biomass) contribute together to the observed brightness temperature. Appropriate corrections for soil moisture must be made in order to make reliable biomass estimations.

The air temperatures given in Table 1 and the ground truth data given in Table 2 have been used to calculate the brightness temperatures using the forest model. The model results and the measured brightness temperatures (Table 1) are plotted in Figures 10 and 11 for the APR and APM sites respectively. The model captures the trends in the data for both sites reasonably well. The model does very well at the APR site (Figure 10) on Augest 27 and November 15, but there is a large disagreement on July 7. The rather complicated trend in the data at the APM site is reflected reasonably well by the model (Figure 11). It is believed that some of the error in Figure 10 is related to the uncertanty in the physical temperature of the canopy. The temperatures (obtained from the weather station at the Wake-field airport) may not be representative for the APR site. This may be due to the fact that the APR site consists of small trees and the canopy and surface temperatures may not be as stable as the APM site.

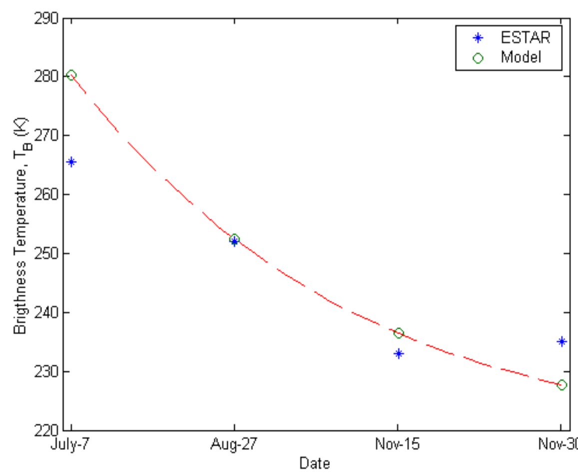

Figure 10. Comparison of ESTAR and model results for APR site

7. CONCLUSIONS

The measurements at Waverly, Virginia have demonstrated that L-band brightness temperature is sensitivity to forest biomass. Although the biomass of the stands observed was between 20 and 200+ tons/ha, it appears that higher values of biomass can be detected by a passive L-band sensor. A discrete model of two forest sites at Waverly was used to simulate the measurements with a reasonable degree of accuracy. They show that soil moisture variation becomes an increasing contributor to the brightness temperature as the stand size becomes smaller. These results also indicate that periods of high soil moisture have the lowest ground contribution and thus afford the best opportunity to monitor biomass.

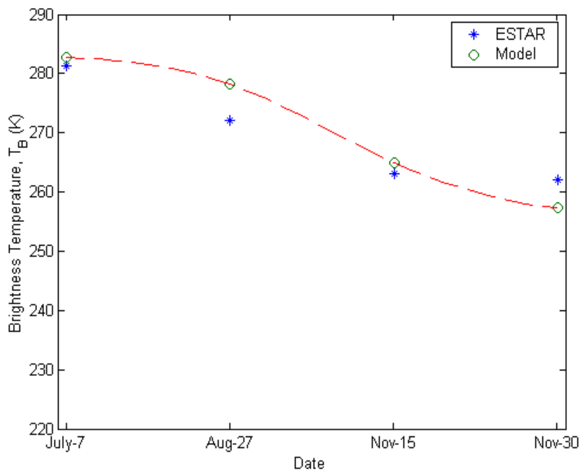

Figure 11. Comparison of ESTAR and model results for APM site

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