Proposal: Joint Fire Sciences Program Solicitation 2001-1

Task #4: Develop, apply, and validate improved aircraft or satellite-based remote sensing applications for quantifying fuel types, fuel condition loading, fire hazard, fire behavior, and effects such as fire distribution and severity. Approaches must be validated by, and linked to, ground measurements.

Project Title: **The Use of High-Resolution Remotely Sensed Data in Estimating Crown Fire Behavior Variables**

Principal Investigator(s): Dr. Gerard Schreuder, Dr. James Agee, and Mr. Doug St. John

Signature: ______________________________

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Duration of Project: September, 2001 – September, 2004

Annual Funding Requested from the Joint Fire Science Program:

2001: $245,033 2002: $241,901 2003: $212,486

Total Funding Requested from the Joint Fire Science Program: $699,420

Total Value of In-Kind and Financial Contributions: $ $474,500

Abstract: Fire researchers and managers are dependent upon accurate, reliable, and efficiently obtained data for the development and application of crown fire behavior models. In particular, reliable estimates of critical crown characteristics, including crown bulk density, canopy height, crown base height, and canopy closure are required to accurately map fuel loading and model fire behavior over the landscape. The emergence of a new generation of high-resolution remote sensing systems in recent years, as well as the development of more accurate field measurement techniques, could allow for more accurate and efficient estimation of crown fire behavior variables. With spatial resolutions often less then one meter, the spatial data provided by these sensors can support more detailed measurement of the forest canopy structure. However, there is a need for the development of analytical techniques to automatically and efficiently extract the required information from the enormous quantity of data provided by these high-resolution remote sensing systems, as well as to assess their utility and cost-effectiveness for the application of fire behavior modeling. We propose to carry out an extensive investigation of the utility of A) active infrared (LIDAR) sensor data and B) active microwave (IFSAR) sensor data for this application, and to compare remote sensing estimates with field-based techniques for the estimation of crown fire fuel density, type and condition.

Federal Cooperators and Contributions:

Primary Federal Cooperator:
USDA FOREST SERVICE PNW RESEARCH STATION
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Collaborators:
Dr. Andrew Youngblood, PNW Research Station, La Grande, OR
Elizabeth Reinhardt, RM Research Station, Missoula, MT
Roger Ottmar, PNW Research Station, Seattle, WA
JoAnn Fites-Kaufman, USFS R-5, Lake Tahoe, CA

In-Kind and Financial Contributions:

LIDAR acquisition (Capitol Forest, 1998 & 1999)	$30,000
Topographic survey(Capitol Forest)	30,000
Field plot establishment (108 plots x $1000/plot)	108,000
2000 PNW/Fort Lewis Cooperative Agreement	37,000
Total	205,000

US DEPARTMENT OF DEFENSE
Dr. Jeff Foster
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In-Kind and Financial Contributions:

LIDAR acquisition (Fort Lewis, 2000)	34,000
Topographic survey	59,000
Support for PhD student	37,000
Total	130,000

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Total Value of In-Kind and Financial Contributions from Federal Cooperators:	**$335,000**

Non-Federal Cooperators and Contribitions:

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In-Kind and Financial Contributions:

LIDAR acquisition (Capitol Forest, 2000)	$ 30,000
Salary (Dr. Agee, 1 month x 3 years)	30,000
Salary (Dr. Schreuder, 1 month x 3 years)	30,000
ATI LIDAR project support	37,500
Total	127,500

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In-Kind and Financial Contributions:

Aerial photography acquisition (Capitol Forest)	2,000
Photogrammetric and GPS survey (Capitol Forest)	10,000
Total	12,000

Total Value of In-Kind and Financial Contributions from
Non-Federal Cooperators : **$139,500**

The Use of High-Resolution Remotely Sensed Data in Estimating Crown Fire Behavior Variables

Project Justification

Across the American West, severe fire problems have been evident for at least two decades. The paradox of effective fire exclusion is that as we have become more successful at excluding fire from the forest, the problem has only gotten worse (Brown and Arno, 1991). Many forest types that historically supported only surface fires now commonly experience torching and active crown fire spread (Agee 1993). Although our current ability to model crown fire is rather crude, current and future models will likely require better information about fuels in the tree canopy.

At the stand level, techniques for evaluating crown fuels were developed by Sando and Wick (1972). They developed a computer program to graph the distribution of crown mass by canopy height. Based on assumptions about crown dimensions, total crown weight was distributed vertically for each tree in the stand and summed across all trees to create a canopy fuel profile. This technique was used by Kilgore and Sando (1975) to evaluate the vertical distribution of oven-dry crown mass before and after burning in a giant sequoia (*Sequoidendron giganteum*)-mixed conifer forest.

A crown fire model was developed by Van Wagner (1977) and based on empirical measurements in relatively simple boreal forest structure. The model had two major components: a threshold for crown fire initiation and thresholds for active crown fire spread. The crown fire initiation component is based on two variables: height to live crown and foliar moisture content (Alexander 1988). The crown fire spread component is based on achieving a critical mass flow rate of fuel (S) defined as the product of rate of spread (R) and crown bulk density (d). Above a critical mass flow rate (S) of 0.05 kg m^2 sec^{-1}, crown fire was enabled. Van Wagner (1993) applied this model to jack pine forests and defined a threshold for active crown fire spread rate (RAC) as 3.0/d, where 3.0 is an empirical constant and d is crown bulk density. Critical to all of these calculations is an estimate of crown bulk density.

Recent efforts to define crown bulk density at a stand level have been crude. Data from Brown (1978) are often used, but he measured open-grown trees, so that the data aggregated at a stand level likely overrepresent values of crown bulk density. Agee (1996) using crown weight data from Brown (1978) estimated crown bulk density for second-growth mixed conifer stands in eastern Washington, noting that the data applied to single-sized, non-stratified stands, and that values for dense stands were likely too high. Stephens (1998) and Graham et al. (1999) also reference Brown (1978) as their source but provide little information about how they calculated crown bulk density. Stephens uses only two values (0.15 and 0.3 kg m^{-3}) and Graham et al. (1999) also provide little information about how they adapted Brown's data.

The deterministic fire growth model FARSITE (Finney 1998) incorporates the use of a geographic information system to compute the spread of fire. FARSITE can run using surface fire algorithms only, based on the Rothermel spread model (Rothermel 1972), or can supplement the surface fire spread by "enabling" crown fire spread using the Van Wagner (1977, 1993) model. If active crown fire spread is enabled, the fire is spread using an adjustment to NFFL fuel model 10 (Rothermel, 1991). Crown bulk density is one of the eight landscape variables that must be available to run the program (the others are elevation, slope, aspect, surface fuel model, canopy cover, canopy height, and crown base height). An attempt to develop input data layers for FARSITE in the Selway-Bitterroot Wilderness Complex (Keane *et al.*, 1998) used a Delphi process to assign canopy height and crown base height. They used an unreferenced table to assign crown bulk density (their Appendix G) across a range of values from 0.09-0.30 kg m^3. Defining absolute thresholds for crown bulk density may be difficult (Agee *et al*. 2000) until better estimates of the parameter can be made.

Accurate estimates of canopy height, height to live crown, canopy cover, and crown bulk density would improve the data layer creation process for FARSITE or future fire spread models. Ground truthing can directly provide canopy height, height to live crown, and canopy cover. Based on a ground-truthed tree list, crown bulk density can be calculated from stand growth models such as the Forest Vegetation Simulator (FVS) (Wycoff *et al*. 1982, Moeur 1985). Williamson (1999) used this approach to evaluate crown bulk density by canopy layer for riparian and upland stands in the Blue Mountains of Oregon (Figure 1). If such variables could be accurately estimated from remotely-sensed data, the application of fire spread models to landscapes would be significantly improved.

The emergence of a new generation of high-resolution remote sensing systems in recent years could potentially allow for more accurate and efficient estimation of crown fire behavior variables. With spatial resolutions often falling in the sub-meter range, the spatial data provided by these sensors can support more detailed measurement of the forest canopy structure, which in turn can increase the accuracy and effectiveness of existing fire behavior models. In particular, the ability of active infrared (laser) and microwave (radar) airborne sensors to penetrate the canopy can significantly improve estimation of the quantity and distribution of crown mass. However, there is a need for the development of analytical techniques and algorithms to automatically and efficiently extract the required information from the enormous quantity of data provided by these high-resolution remote sensing systems, as well as to assess their utility and cost-effectiveness for the application of fire behavior modeling.

Project Objectives

We propose to carry out an extensive investigation of the utility of A) active infrared (LIDAR) sensor data, B) active microwave (IFSAR) sensor data, and C) field-based techniques for the estimation of crown fire fuel density, type and condition. This project will complement and support JFSP –funded fuels mapping and characterization efforts currently underway at the national, state, and local levels (Ottmar, 2001).

A. The LIDAR remote sensing technology

Study motivation

LIDAR (**Li**ght **D**etection **A**nd **R**anging) is an operationally mature remote sensing technology that can provide detailed geometric (XYZ position of reflecting surface) measurement of the forest canopy and the ground surface. In forested areas, LIDAR pulses bounce back from foliage and branches composing the canopy (see Figures 3 & 4). LIDAR can therefore provide detailed information relating to the vertical distribution of canopy biomass -- measurements that can provide direct spatial data inputs to wildland fire behavior models such as FARSITE. In particular, analysis of the spatial distribution of LIDAR returns within a specified grid cell area (see Figure 5) could yield estimates of numerous spatial variables critical to fire behavior modeling – ground elevation, slope, aspect, height to base of live crown, canopy height, and crown bulk density.

Background

A LIDAR sensor system essentially works upon the principle of measuring the time interval between the transmission and reception of laser pulses transmitted in a known direction and from a known position, acquired (respectively) by an integrated IMU (**I**nertial **M**easurement **U**nit) and airborne GPS (**G**eographical **P**ositioning **S**ystem).

The nominal accuracy of small footprint LIDAR measurements is 1 m (horizontal) and 10 cm (vertical). These sensors typically acquire from 10,000 – 20,000 range measurements per second, with an average density of 4 pts/m^2 – 0.2 pts/m^2.

While to date most of the emphasis in LIDAR research has been on terrain measurement and modeling, there has been increasing interest in the use of LIDAR for detection and measurement of forest features. Several research studies have looked at the use of small footprint LIDAR systems to estimate forest stand level parameters (Nelson *et al*, 1988; Naesset, 1997; Means *et al*, 2000). Recently, researchers have investigated the use of large footprint SLICER data for analysis of forest structure (Lefsky *et al*, 1999). These studies found that forest structure could be characterized through analysis of the continuous laser backscatter waveform; however, the detailed mapping capabilities of this sensor are somewhat limited due to its low spatial resolution.

Research carried out in Canada has established the validity of a probabilistic model-based approach to measuring forest canopy characteristics with LIDAR data. Magnussen and Boudewyn(1998) looked at the distribution of LIDAR canopy heights as a function of the vertical distribution of foliage area. They found that the proportion of lidar returns above a specific height was directly proportional to the fraction of leaf area above this height, and that the quantile of the LIDAR height measurements was an unbiased estimator of the fraction of leaf area above a given. While this study has established an empirical relationship between the distribution of LIDAR returns and leaf area, other studies have used a simulation-based approach using Monte Carlo ray tracing models to investigate the physical relationship between the spatial distribution of forest structural components and the LIDAR data (Govaerts, 1996; Sun and Ranson, 2000).

Methods

We propose to investigate the potential utility of small footprint LIDAR data for providing information relating to type, condition, quantity and spatial distribution of crown fuels. It is expected that in dense canopies, fewer LIDAR pulses will penetrate deeply into the canopy, while in less dense canopies the pulses may respond as multiple returns from the canopy, understory, and the ground surface. Given the complex spatial relationships both between the unobserved canopy parameters and between the observed LIDAR returns, the most appropriate approach to modeling of this data will use Bayesian statistical inference. (Gelman *et al*, 1995). This approach uses an explicit probabilistic relationship between the height of the LIDAR returns and the distribution of crown biomass, and essentially identifies the most likely values of the parameters of this vertical distribution of crown biomass, given the observed LIDAR data in a specified area. This approach has the following steps:

1. Model spatial distribution of crown biomass (denoted as $\mathrm{Prob}(X)$) as a mixture of distributions representing different canopy components/strata (see Figure 4).

2. Model heights of LIDAR returns *given* the parameters of crown biomass distribution (denoted as $\mathrm{Prob}(Y|X)$) (see Figure 4).

3. Use Bayes theorem to carry out inference on the parameters of the spatial crown biomass distribution. This uses the relationship: $\mathrm{Prob}(X|Y) \propto \mathrm{Prob}(Y|X)\ \mathrm{Prob}(X)$

This approach allows for predictions to be made, on a probabilistic basis, regarding 1) the height to crown base, 2) canopy height, 3) canopy bulk density, and 4) elevation. If these estimates are made at each grid cell, estimates of canopy coverage over the landscape can be carried out as well.

The physical relationship between the distribution of the LIDAR returns and the distribution of crown biomass can be investigated and modeled using a Monte Carlo ray tracing simulation approach, which can in turn be used to develop the probability model. The estimates generated from this approach will be compared to field measurements of canopy characteristics and terrain, and LIDAR-derived estimates of crown bulk density will be compared to those generated from the COVER extension of the FVS growth-and-yield model to assess the utility of this remote sensing approach in comparison to existing field-based techniques.

Additional considerations

The costs of LIDAR acquisition are steadily declining, indicating that this technology should provide a cost effective alternative to field measurement of crown fire behavior variables. It is expected that this data could be available at a cost of < $1/acre, making it competitive with existing remote sensing techniques and significantly less expensive than field-based approaches. As an optical sensor, LIDAR does have limitations as a source for spatial data acquired over extensive areas. LIDAR does not have the capability to penetrate cloud cover and therefore its availability is weather-dependent, an important consideration for real time data acquisition under adverse atmospheric conditions. In contrast, sensors operating in the microwave range of the electromagnetic spectrum, such as radar, do not have this limitation.

B. IFSAR remote sensing technology

Study Motivation

There is also tremendous potential for the use of IFSAR (**I**nter**f**erometric **S**ynthetic **A**perture **R**adar) to estimate fire behavior variables over large areas at relatively low cost and with an all-weather capability. It is believed that this information derived from interferometric radar data could be directly related to the crown fire behavior variables that are important as inputs to current fire behavior models. In addition, backscatter intensity in radar images is related to foliage moisture, another variable that is of great importance in fire modeling.

Background

SAR (**S**ynthetic **A**perature **R**adar) is an active sensor system that operates on the same principles as LIDAR except that it emits microwave radio energy with wavelengths of 0.001 - 1 meter. The information content of radar data in forested terrain varies depending upon the wavelength (λ) of the transmitted pulses – energy with short wavelengths ($\sim 10^{-2}$ m) is reflected from the canopy surface while radar energy with longer wavelengths ($\sim 10^{-1}$ m) penetrates the foliage in the canopy and reflects from tree trunks and the terrain surface. The resulting image represents the intensity of the radar backscatter throughout the illuminated region. The use of SAR backscatter data for forest structure analysis has been an extremely active area of research over the last two decades (Hussin *et al*, 1991; Sun and Ranson, 1995). However, due to various geometric distortions inherent to the radar sensing process, it is impossible to acquire three dimensional information (i.e. canopy and/or terrain heights) from a single SAR image.

The availability of interferometric radar (IFSAR) data in recent years has the potential to significantly extend the applicability of radar analysis for forest measurement. Radar interferometry uses the difference in phase, or phase shift, between two radar images acquired from slightly different locations to acquire information relating to the elevation angle to an imaged point, which is used in conjunction with the range information to determine the three-dimensional location of this imaged point (Hagberg *et al*, 1995). Varying the wavelength of the emitted energy will result in the generation of different three-dimensional surfaces – sensors emitting pulses with short wavelength (i.e. X-band IFSAR with $\lambda \approx 3$ cm) can generate a surface of the forest canopy, while sensors with longer wavelengths (P-band IFSAR with $\lambda \approx 72$ cm) will generate a terrain surface (Hofmann *et al*, 1999). Accuracies of these systems also vary with wavelength; X-band interferometric radar can have spatial resolutions of 0.5 meters with a vertical accuracy of 0.05 m, while P-band IFSAR has spatial resolution of 3 m with a vertical accuracy of 0.5 m.

Researchers have shown that interferometric radar data acquired from sensors with wavelengths in the intermediate range (C-band IFSAR with $\lambda \approx 5.6$ cm) can be used to extract information relating to the depth of various vegetation layers, the density of the scattering medium (related to biomass), and the elevation of the terrain surface (Treuhaft *et al*, 1996). While these researchers assumed a homogeneous density for the vegetation layer in their case study to reduce the number of parameters in the model, they have established the theoretical basis for more complex, and realistic, inferential approaches to the estimation of canopy density characteristics from IFSAR data. It should also be noted that this study utilized a system with a single (C-) band, which has limited ability to penetrate the forest canopy in comparison to IFSAR systems with longer wavelengths (i.e. P-band). As these authors have noted, it is expected that accuracy in the estimation of vegetation density and canopy characteristics will improve significantly through the analysis of multifrequency IFSAR data.

Methods

We propose to use a Bayesian statistical modeling approach to carry out inferences on fire behavior variables by modeling the observed cross-correlation amplitude, cross-correlation phase and backscatter intensity of multifrequency interferometric radar data as a function of the unobserved canopy structure parameters (see description of Bayesian inferential approach in LIDAR methods section above and Figure 4). As noted above, Bayesian inference is appropriate for an image analysis problem in which underlying scene characteristics (i.e. vegetation and canopy characteristics) are not observed, but can be related to the observed image through a probability model (conventionally termed the *likelihood* model). In this framework, prior information relating to the distribution of scene components and expected regularity within the image is incorporated into the model in the form of a *prior* probability distribution. Advanced statistical inferential techniques, such as Markov chain Monte Carlo (MCMC), can be utilized to estimate the parameters pertaining to different vegetation layers, including depth, density, and water content.

A Monte Carlo ray tracing simulation model will be utilized to determine the specific nature of the relationship between the observed interferometric cross-correlation and backscatter power and the physical characteristics of the scattering elements composing the forest canopy (wet/dry foliage, stems, branches, etc.). In particular, we expect to develop an estimate of the vertical distribution of crown bulk density for a given cell size directly from the interferometric radar data, as well other spatial inputs to the FARSITE fire behavior model. The results of this radar analysis will be compared to the estimates of crown fire behavior variables obtained by optical sensors (LIDAR) and traditional field-based methods.

Additional considerations

The cost of IFSAR data acquisition over extensive areas will likely be significantly lower than that of other active remote sensing technologies, including LIDAR. IFSAR can be acquired from a jet aircraft platform flying at relatively high altitudes (6000 – 12000 meters), enabling the acquisition of data over large areas in a short period of time (3600 – 7200 km^2 /hr), day or night, and through cloud cover. IFSAR, therefore, has a distinct advantage over optical remote sensing technologies if real time data acquisition is needed under adverse atmospheric conditions such as the presence of clouds or smoke.

C. Comparison of Remote Sensing Estimates to Field-based Crown Fuels Measurement

Study motivation

Estimation of crown fire behavior variables has traditionally been based upon ground measurements. However, field measurement techniques are not standardized and are not consistently applied across agency boundaries, which can complicate and frustrate efforts to model fire behavior at the landscape scale. There is a need for a standardized, efficient approach to measuring crown fire fuels in forest stands exhibiting a wide variety of structural characteristics. In addition, this information from crown fuel measurements collected in the field needs to be integrated with information derived from remotely sensed data in a statistically robust approach to maximize the accuracy of fire behavior modeling.

Background

Estimates of crown base height and canopy height can be obtained from routine stand inventory data. Aspect and elevation can be derived from a digital terrain model of the area, while estimates of crown bulk density can be generated from a tree list using a stand growth-and-yield model such as FVS.

A current JFSP-funded project is comparing alternative techniques for measuring crown fuels, based upon leaf area measurements, with standard forest inventory techniques in conifer forests (Reinhardt, 2001). This study is comparing these indirect measurements to a direct measurement of crown biomass, and will attempt to develop and verify a consistent method for measurement of crown fuels across agency boundaries.

Another JFSP-funded project is developing a fuels inventory and mapping system for the Sierra Nevada bioregion using remotely sensed data in combination with field measurements of canopy structure (Fites-Kaufman, 2001).

Methods

We propose to utilize the tremendous amount of ground truth inventory data that is currently available to us (see Study Areas and Datasets section of this proposal) and to collect additional field data in order to both 1) validate remotely sensed estimates of crown characteristics, and 2) develop an integrated approach to measurement of crown fuels incorporating both field measurements and remotely sensed data.

In addition, we will utilize the large number of topographic survey measurements, acquired throughout both the Capitol Forest and Fort Lewis study areas, to assess the absolute accuracy of biomass spatial distributions that are estimated from remotely sensed data.

Additional field measurements will be carried out on all study areas, and will be based upon the field-based techniques developed by the crown fuel measurement studies currently underway at the USFS Rocky Mountain Research Station Fire Sciences Lab (Reinhardt, 2001) and the USFS Pacific Southwest Region AMS Enterprise Team (Fites-Kaufman, 2001). It is expected that the establishment of sample plots and acquisition of field data will be a major component of the PhD-level RA appointment (see budget allocation).

Study Areas and Datasets

Existing study sites include several Douglas-fir stands in Fort Lewis, WA and over two square miles within Capitol State Forest, WA. The Capitol Forest study area has a variety of different stand ages and treatments (group selection, patch, thinning, two-age, clear-cut, and control). Existing data sets include:

- LIDAR data sets from both helicopter and fixed wing platforms with varying densities (high-density helicopter data acquired for Capitol Forest, 1998 & 1999, medium-density fixed-wing data acquired over Capitol Forest and Fort Lewis, 2000)
- Large scale (1:3000) and medium scale (1:7000 and 1:12000) aerial photography with a variety of emulsions (normal color, color infrared, B&W) and orthophotos.
- 350 surveyed ground topography points under forest canopy
- High quality photogrammetric mapping
- 108 1/5th acre inventory plots in Capitol Forest with measurements of tree height, height to base of crown, diameter at breast height (DBH), species, crown class, condition. Stem locations were measured on a selection of these plots.
- 25 sample plots in Fort Lewis with measurements of tree height, height to base of crown, DBH, species, crown class, and stem locations.

It is expected that IFSAR will be acquired over the Capitol Forest and Fort Lewis study sites as well.

In addition, field measurements and remotely sensed data will be acquired for study areas within the Metolius Research Natural Area (RNA) and the Pringle Falls RNA, two high-risk fire sites on the east side of the Cascades near Bend, OR. Dr. Andrew Youngblood (PNW Natural Disturbance Program) has established and stem mapped twelve 1-ha plots in the Metolius RNA and five 1-ha plots in the Pringle Falls RNA. The plots are within Ponderosa pine stands that have a dense understory of pine, and are part of a study to investigate the reintroduction of fire into late-successional Ponderosa pine stands. It is expected that additional field measurements will be acquired over this eastside site as well, implementing techniques developed in current JFSP fuels measurement projects. Investigation of other vegetation/fuels types would be covered in a later proposal if this work proves successful.

Project duration

November, 2001 – December, 2004

Deliverables

We expect to produce algorithms and associated software tools that allow specialists to estimate spatially explicit canopy fuels over a landscape. These tools will provide estimates of crown bulk density, stand height, crown base height, and canopy closure. The software will meet the following specifications:

- Software tools will use a graphical user interface (GUI) for user interaction
- All computationally expensive algorithms will be written in compiled (C/C++) programming languages.
- Various spatial data inputs (LIDAR, IFSAR, imagery) will be allowed.
- Output will be in a format (English and metric units) that can be easily input into the FARSITE or other comparable, widely-used fire behavior model.
- Spatial resolution ("pixel size") of output data will be variable, depending upon user requirements.

Timeline (see figure below)

November, 2001: Review project outline with JFSP. Identify specific product requirements of user groups; preliminary results will be demonstrated to cooperating federal agencies.

April, 2002: Presentation of preliminary results to cooperating agency personnel. Review of agency product requirements.

September, 2002: Presentation of preliminary results to cooperating agency personnel. Demonstration of specific functionality of beta version of product.

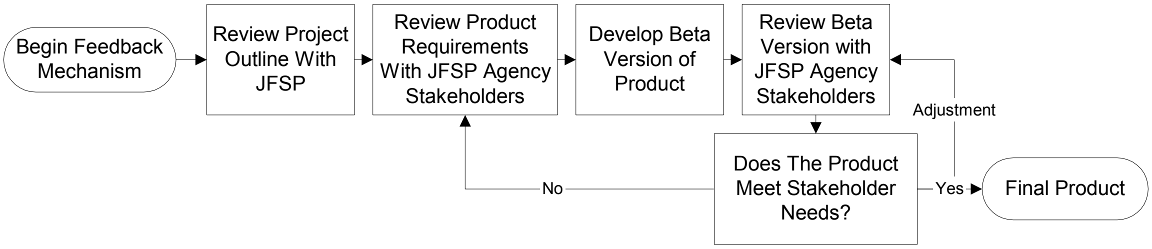
April 2003: Demonstration of beta version of product(s). Discuss functionality of beta version with respect to agency product requirements.

September, 2003: Discuss functionality of beta version with respect to agency product requirements. Outline process for evaluation of product by JFSP cooperating agencies.

April, 2004: Discuss results of product evaluation and identify necessary final adjustments to product.

December, 2004: Product(s) delivered in final form by September, 2004.

Product Improvement Feedback Mechanism.



Technology Transfer

Publications and attendance of symposia will provide exposure for the project. Two half-day workshops will be conducted at the University of Washington College of Forest Resources in 2002, 2003, and 2004. The earlier workshops (in 2002 and 2003) will facilitate dialogue on product requirements of federal agencies, the later workshops (2004) will provide user groups with training on final products. This will be integrated with the product improvement feedback mechanism described under Deliverables. We expect these workshops to be two-way interaction, providing technology transfer and product improvement. Printed material, posters, and on-site user demonstrations will be provided as needed. Software, training materials, and other products will be accessible from a maintained website.

Proposed Budget

Project Title: **The Use of High-Resolution Remotely Sensed Data in Estimating Crown Fire Behavior Variables.**
Principal Investigator(s): Dr. Gerard Schreuder and Dr. James Agee
Proposed Award Period: November, 2001 – December, 2004

*** Due to the Cooperative Agreement between the University of Washington and the PNW Research Station, no overhead/indirect costs would be incurred for this project.**

**** Justification of need for salary support: Both principal investigators hold 9-month tenured faculty appointments at the University of Washington.**

Budget

Salaries	**Notes**	**Year 1**	**Year 2**	**Year 3**	**Total**
Post Doctoral Fellowship (1)		$60,000	$62,400	$64,896	$187,296
Principal Investigators (2)	(2 weeks each)	$9,270	$9,641	$10,027	$28,938
PhD Level Research Assistants (2)	($24,660 each)	$49,320	$51,293	$53,345	$153,957
Hourly Assistance		$10,000	$10,400	$10,816	$31,216
Benefits	**Rates**				
Post Doctoral Fellowship (1)	24.20%	$14,520	$15,101	$15,705	$45,326
Principal Investigators (2)	21.80%	$2,021	$2,102	$2,186	$6,308
PhD Level Research Assistants (2)	10.20%	$5,031	$5,232	$5,441	$15,704
Hourly Assistance	10.60%	$1,060	$1,102	$1,146	$3,309
Total Salaries & Benefits		**$151,222**	**$157,271**	**$163,562**	**$472,054**

Contract Services	**Notes**	**Year 1**	**Year 2**	**Year 3**	**Total**
Data: LIDAR, IFSAR, Aerial Photography		$30,000	$50,000	$20,000	$100,000
Telecommunications		$2,000	$2,000	$2,000	$6,000
Copying		$2,000	$2,000	$2,000	$6,000
Postage		$500	$500	$500	$1,500
Publications		$1,000	$1,000	$1,000	$3,000
Total Services		**$35,500**	**$55,500**	**$25,500**	**$116,500**
Travel					
Conferences, Airfare, Lodging		$8,000	$12,000	$8,000	$28,000
Supplies & Materials					
Software		$10,000	$1,000	$1,000	$12,000
Lab Supplies		$800	$800	$800	$2,400
Field Supplies		$300	$300	$300	$900
Total Supplies & Materials		**$11,100**	**$2,100**	**$2,100**	**$15,300**
Equipment	**Notes**				
Computer	2 workstations and printer	$20,000	$0	$0	$20,000
Field		$5,000	$1,000	$1,000	$7,000
Total Equipment		**$25,000**	**$1,000**	**$1,000**	**$27,000**
Total Direct Costs		**$230,822**	**$227,871**	**$200,162**	**$ 658,854**
PNW Station Overhead (5.8%)		$ 14,212	$ 14,030	$ 12,324	$ 40,566
Total JFSP Funds Requested		**$245,033**	**$241,901**	**$212,486**	**$ 699,420**

Literature Cited

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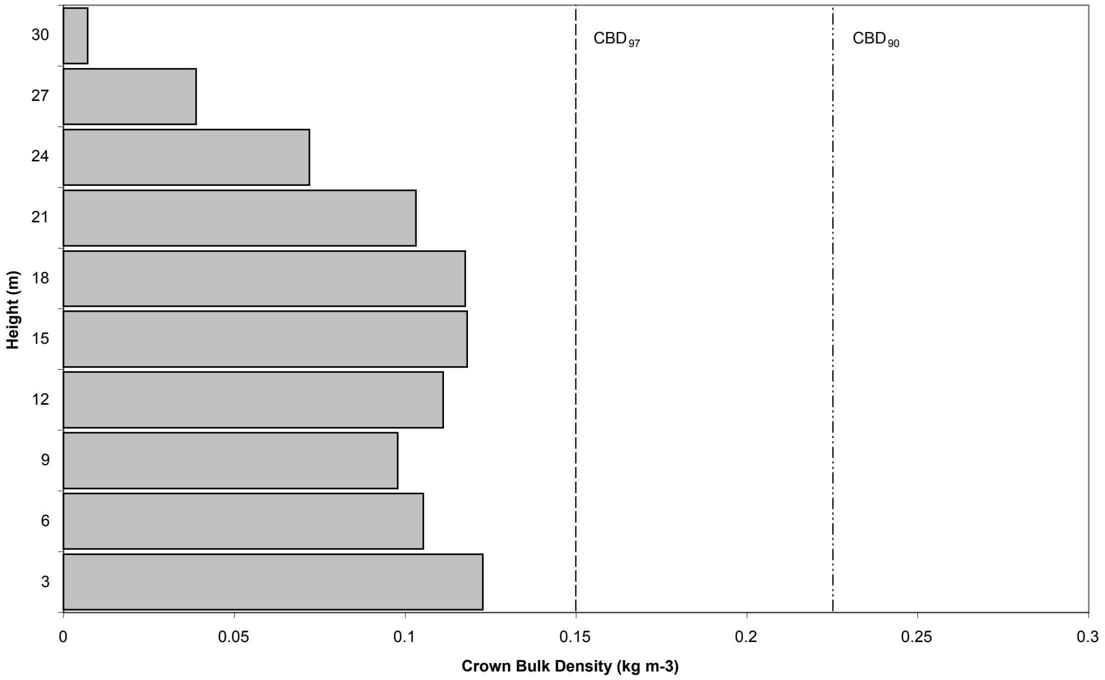
Figure 1. Crown bulk density profiles for a stand with no crown fire potential and a stand with crown fire potential (CBD_{90} and CBD_{97} represent critical crown bulk densities required for active crown fire spread under 90 and 97 percentile fire weather, respectively, for the Blue Mountains, Oregon). Profiles created through FVS, CANOPY extension.

A. Stand with No Crown Fire Potential



B. Stand with Crown Fire Potential

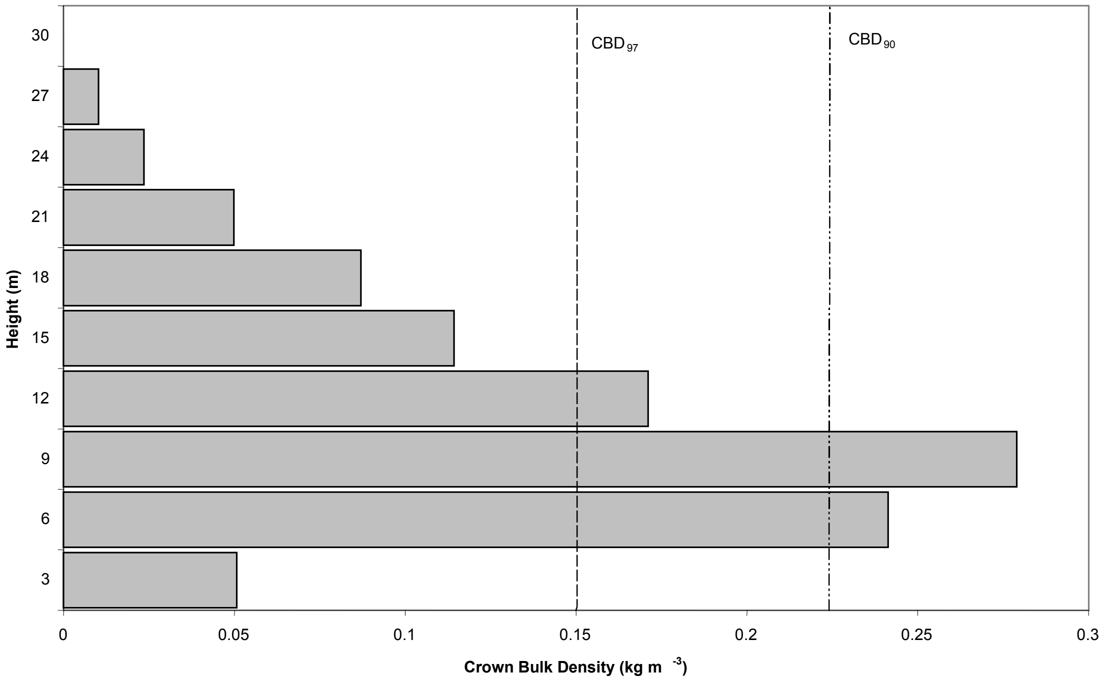


Figure 2. Aerial photograph of mature Douglas-fir stand, Fort Lewis, WA.

Figure 3. Lidar returns within mature Douglas-fir stand shown above, Fort Lewis, WA

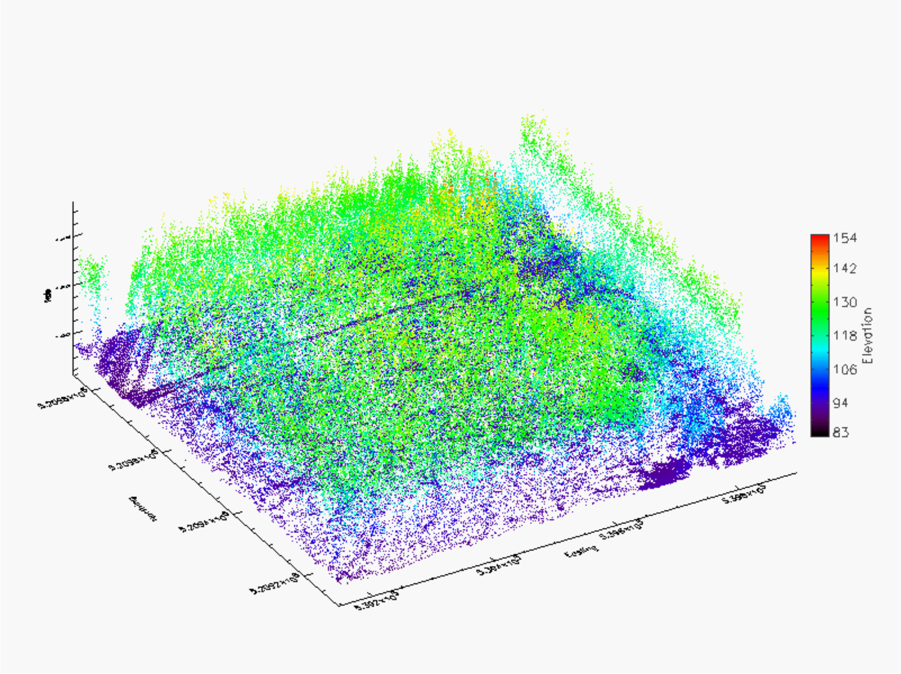


Figure 4. Distribution of LIDAR elevations (bars) and hypothetical distribution of canopy biomass (line) for 900 m^2 area within mature Douglas-fir stand shown above, Fort Lewis, WA.