

1. Research Objectives

We propose to use the SRTM (Shuttle Radar Topography Mission) data to map the surface aerodynamic roughness length over the entire area covered by the shuttle mission between 60° N and 57° S. To calibrate, validate, and assess the accuracy of this map over various land cover types, in particular over the tropical forest, we propose to use (1) the VCL (Vegetation Canopy Lidar) data, (2) simultaneous airborne laser altimeter and AIRSAR data acquired in California and during the Pacific Rim campaign, and (3) ground data collected during the LBA campaign in the Amazon basin and other large scale field data available in the literature (e.g. BOREAS). Moreover, we intent to demonstrate the use of such map in characterizing the atmospheric boundary layer by using a GCM type model developed at the Colorado State University.

The following sections elaborate on the scientific rationale, approach and detailed work plan for the proposed work.

1.1 Introduction

Realistic models of land surface-atmosphere interactions were introduced into general circulation models of the atmosphere (GCMs) in the mid-1980 (Dickinson, 1984, (Sellers et al., 1986). These land surface parameterization were based on simple formulations of the processes of radiative transfer (albedo), turbulent transfer (roughness length) and evapotranspiration (surface resistance) associated with vegetated surfaces to describe the exchanges of energy, momentum, and sensible and latent heat, respectively, between the vegetation-soil system and the lowest atmosphere layer of a GCM. In general these models suffer from several shortcomings, in particular, the paucity of global data on some input parameters. Currently, the GCM models function at a coarse resolution using 1° by 1° grid data, but the sub-models (mesoscale) operate at smaller resolution and therefore require finer scale data sets.

The lack of data on vegetated surfaces has also limited our understanding of climate change/variability and its relation with the status and dynamics of the biotic changes of land surface. With the initiative of the NASA's Mission to Planet Earth

(MTPE) program, several studies have been carried out within the earth science disciplines such as ISLSCP and large scale field experiments (FIFE, HAPEX, BOREAS, LBA). Following these studies it was recognized that satellite data offers the most economic and consistent means to provide some of the data required by modelers at various scales (Asrar and Dozier, 1994; Sellers et al., 1994). So far the main source of data for deriving the required parameters for land-surface atmospheric and climate studies has been the AVHRR instrument. Sellers et al., (1994) and Los et al., (1994) outline the estimation of these parameters from the AVHRR data. Three essential parameters: albedo, surface roughness, and surface conductance, were derived from the AVHRR 1° by 1° normalized difference vegetation index (NDVI). In addition, the same data set was used to derive land cover types and other vegetation characteristics such as FPAR (Fraction of Photosynthetically Active Radiation), LAI (Leaf Area Index) which were used directly in GCM or SiB2 (Simple Biosphere Models) (Sellers et al., 1994; Sellers et al., 1996a,b).

While these derived parameters from the AVHRR data represent a significant contribution in simulating the global surface energy balance and flux exchange, there are considerable uncertainty associated with the estimated parameters. Satellite instruments such as MODIS are designed to improve these uncertainties and provide more reliable data at finer resolution (Running, et al., 1994). However, direct measurements of canopy structural parameters such as height, fraction cover, roughness, and biomass are not included in any of the EOS (Earth Observing System) missions. Recently, the NASA's Earth System Science Pathfinder (ESSP) program was designed to respond to research priorities and measurement of surface parameters that were not adequately addressed by the EOS space missions. For example VCL (Vegetation Canopy Lidar) was the first mission chosen within the ESSP program to provide reference vegetation height and topography data.

Among the three vegetation parameters surface roughness length has not been addressed directly by any of the EOS or ESSP instruments (surface albedo and conductance will be produced by MODIS). This parameter is crucial in defining the momentum transfer as the primary process in the atmospheric boundary layer models and assessing the changes of land cover on the global climate. Data from two NASA

missions: SRTM and VCL are particularly useful to derive this parameter on a global scale. SRTM will provide SAR interferometric image data for mapping the surface topography and VCL will provide laser altimeter data for measurement of vegetation height. Both data sets, however, are able to map the surface height variation or roughness. The following section describes the aerodynamic surface roughness as used in atmospheric boundary layer problems and the roles of SRTM and VCL measurements to map this parameter on a global scale.

1.2 Aerodynamic Surface Roughness

The aerodynamic roughness length Z_0 is defined as the height where the wind speed becomes zero. In modeling the wind profile and drag over vegetation canopies, the height where the wind speed becomes zero inside the canopy layer is referred as the aerodynamic roughness length of the vegetation. The roughness parameter appears explicitly in the logarithmic wind-profile equation (Monteith and Unsworth, 1990).

This parameter is entirely determined by the structure of vegetation, i.e. the disposition of the biomass in 3-D space. There are many empirical relationships that relate Z_0 to vegetation height. But, according to Garratt (1997), the relationship should also include the density of spacing of vegetation. The relationship, therefore, appears to be nonlinear in a logarithmic sense, such that for the vegetation at a given height, the Z_0 increases as the density increases, till it reaches a maximum and then decrease gradually. This phenomena is not difficult to interpret. When the density of sparsely-placed surface elements (e.g. vegetation components) increases, the drag increases and therefore, also Z_0 ; but when the placement of elements becomes extremely dense, the flow of wind may actually skim over the top of the canopy without entering the space below. Given the logarithmic relationship of the wind speed and observation of the wind speed at two or more heights, it is easy to solve for Z_0 . Once this roughness length is determined for a certain surface, it does not change with wind speed, stability or stress (Stull, 1988). But, the roughness length can change if the structure and density of surface roughness elements change (e.g. because of land cover change, deforestation, soil erosion, etc.).

Although aerodynamic roughness length is not equal to the height of the individual roughness elements on the ground, there is a one-to-one correspondence between them. In fact, for vegetated surfaces the height variation (physical roughness) follows the same behavior as the aerodynamic roughness with respect to the vegetation density. It is also known that if the individual roughness elements are packed very closely together, then the top of those elements begin to act like a displaced surface.

Typically, Z_0 is derived from measurements of the wind velocity profile through the lower atmosphere boundary-layer. Such measurements require elaborate field equipment, including arrays of anemometers on masts, temperature probes, and recording equipment. Moreover, Z_0 values for natural surfaces obtained in this way are limited to immediate sites where such measurements are made. Consequently, very little data on aerodynamic roughness have been obtained, despite the relevance for climate studies and analysis of land-surface atmospheric interactions. Most boundary-layer models use roughness lengths of various land over types from a lookup table (see for example Table 1). Model simulations show that the actual variation of roughness length between a tropical rain forest ($Z_0 = 200$ cm) and a desert of ($Z_0 = 1$ cm) can cause four fold difference in the bulk aerodynamic drag (Sud et al., 1988). By making the surface smoother, models may predict a reduction of rainfall and a substantial shift in its circulation (Sud and Smith, 1985).

To remove the uncertainties of the aerodynamic roughness parameter in boundary-layer models, we propose to measure this parameter from the remote sensing data. By accurately measuring the physical roughness or height variation of the surface from remote sensing data, and using a simple one-to-one relationship between physical roughness and the aerodynamic roughness, this parameter can be mapped accurately over various land cover types. The data from SRTM and VCL can produce a direct measurement of this quantity with high accuracy. The following section describes the characteristics of the data acquired from these two instruments for measuring the surface roughness.

Characteristics of SRTM Data

The Shuttle Radar Topography Mission (SRTM) will collect radar data over the 80 percent of the Earth's land surface between 60° N and 57° S to provide the most precise three-dimensional (3-D) images of the surface (Figure 1). The data will be collected during the 11-day space shuttle mission in late 1999. SRTM is an active remote sensing instrument which is built on radar interferometry technology which compares two radar images taken at slightly different locations to obtain elevation or surface change information. The products are in strip or mosaic form with 30 m resolution and 16 meter absolute height accuracy. Strip Orthorectified Images store the radar image data. These products will not contain one entire datatake. Rather, the output files will be approximately 1100km long and approximately 80km wide. Each output file is a single subswath, where four subswaths equals one swath. At each subswath the polarization of the radar switches between H (horizontal) and V (vertical) After processing, the cross-correlation of images in strip mode at 30 meter spacing will be available to us for this project.

In addition to the topographic information, the interferometric SAR (Synthetic Aperture Radar) data are sensitive to the vertical structure of the vegetation canopies, and could, in principle, provide measurements for surface height variations or roughness. The SRTM radar operates at C-band (6 cm wavelength) and the signal at this wavelength has a significant penetration into the vegetation canopy depending on the vegetation density and moisture content. Even for dense and uniform vegetation the penetration may exceed few meters into the canopy which is sufficient to provide information about how the surface is structured (Ranson and Saatchi, 1992; Rodriguez and Martin, 1992). In recent years, several studies has been performed to analyze the sensitivity of the interferometric SAR data to vegetation structure (Wegmuller et al., 1997). Recently, Rodriguez and Michel (1998) compared the interferometric SAR data at C-band with the laser altimeter over forest landscapes and showed that there is a strong correlation between the two data sets in response to the vegetation height variations. Their results demonstrated that even though laser altimeter signal was superior in giving direct measurements of the vegetation height, the interferometric SAR signal could estimate the height variations or roughness accurately (Figure 2). The extension of this result over arid or semi-arid surfaces has been studied in details by Greeley and Blumberg (1995). They studied the relationship of

physical surface roughness and aerodynamic roughness and the sensitivity of SAR (at non-interferometric mode) for retrieving aerodynamic roughness parameter. They were able to map the roughness length in death valley, California and show how the technique could be extended to vegetation canopies (Greeley et al., 1997; Blumberg and Greeley, 1993; Rasmussen et al., 1993). These results opened up the possibility of using the interferometric SAR data from the SRTM mission for directly measuring the surface roughness.

Characteristics of VCL Data

Vegetation Canopy Lidar (VCL) is the first selected mission of NASA's new Earth System Science Pathfinder Program (ESSP). The principle goal of VCL is the characterization of the three-dimensional structure of the earth, in particular, the vertical and horizontal structure of vegetation canopy and the surface topography. VCL is an active Lidar remote sensing system consisting of a five-beam instrument with 25 m contiguous along track resolution. The five beams are in a circular configuration 8 km across and each beam traces a separate ground track spaced 2 km apart, eventually producing 2 km coverage between 65° N and S. The core measurement objectives of VCL are: (1) canopy top heights; (2) vertical distribution of intercepted surfaces; (3) ground surface topography elevations. During the lifetime of the VCL mission, approximately 4.7% of the land area between 65° N and S will be covered. The data products are at two spatial and temporal resolutions: 1, monthly products and 2 km, 6 monthly products. For example, the vegetation height at 2 km resolution will be provided as along-track, contiguous footprint observations. These observations of derived vegetation height are useful in calibration of SRTM data.

The complementary measurements from SRTM and VCL missions will provide unprecedented opportunity for data fusion and extraction of fundamental parameters about the surface and vegetation structure. We have already demonstrated the height correlation of the two data sets by using pixel by pixel comparison of laser altimeter footprint and IFSAR data over a coniferous forest (Figure 2). Analysis of Figure 2 also shows that when the standard deviation of height over several pixels are compared the

two data sets agree very well. We propose to use the VCL vegetation height measurement to calibrate and validate the derived surface roughness from the SRTM.

1.3 Measurement of Boundary Layer Roughness

The interferometric correlation (i.e., the correlation coefficient between the two interferometric channels—a byproduct of the standard interferometric processing) contains useful information regarding vegetation canopies. Departures from perfect correlation are due to differences in the radar signal between the two interferometric channels. These differences can be due to different thermal noise in the two channels; or more importantly, the slightly different viewing geometry for each channel causes additional deceleration in the two signals. Part of this additional deceleration is due to the angular spread of the radar resolution cell; i.e., the well known van Cattiest Zernike theorem [Goodman, 1985]. It has been shown theoretically [Rodriguez and Martin, 1992], [Treuhaft et al., 1997], [Rodriguez et al., 1999] that an additional amount of deceleration can be related to the amount of volumetric scattering within the radar resolution cell. This volumetric scattering can be due to either penetration into the canopy, or to the fact that the canopy itself presents a rough interface, giving rise to dispersion in the phase [Rodriguez and Martin, 1992]. It is this effect that we propose to use to estimate the aerodynamic roughness.

Treuhaft et al. [1996] introduced a model for the volumetric deceleration which assumed uniformly attenuating flat vegetation canopies. The flat canopy surface and homogeneous canopy make this model of limited usefulness for estimating aerodynamic roughness. Rodriguez et al. [1999] have introduced an alternate non-parametric inversion technique whereby the interferometric correlation is used to obtain an estimate of the height variance of the canopy scattering sources, which can be either due to penetration through the canopy gap structure, or due to the height variations of the canopy itself.

As a validation of this non-parametric scatterer height variance estimation technique, an experiment was conducted employing the JPL TOPSAR C-band (5.6 cm wavelength) interferometer and the Goddard laser profilometer. The scene studied

contained a variety of canopy types, ranging from mature heterogeneous coniferous forests, to homogeneous stands at various stages of regrowth. Figure 3 shows a comparison of C-band interferometer estimated scatterer rms roughness obtained by the JPL TOPSAR instrument for a coniferous forest in the Guifford-Pinchot National Forest, WA. An estimate of the optical canopy closure, and the corresponding scatterer height variance, was obtained from the laser data, and this is shown for comparison in the same figure. As can be seen, there is a strong correlation between these two quantities, indicating that the interferometer and laser have similar penetration characteristics into the canopy; i.e., geometric blockage due to either tree height variations or the canopy gap structure are the dominant mechanisms governing the scattering. The close agreement between the two data sets (in most cases at submeter level) indicates that the interferometric measurement can be used to extend the laser measurement of canopy roughness beyond the laser footprint. It is this property which we propose to use to characterize aerodynamic roughness.

Interferometric volumetric deceleration sensitivity is governed by the ratio of the interferometric baseline to the range. While SRTM and the JPL TOPSAR have very different baselines (60m and 2m, respectively), their baseline to range ratio, and the range of incidence angles observed, are very similar, indicating the feasibility of using SRTM for canopy measurements. The main difference between the two systems consist in the reduced range resolution of SRTM (30 m) compared to TOPSAR (15 m). This difference in resolution gives rise to different amounts of deceleration due to the van-Cattiest Zernike effect. However, this effect is deterministic once the scattering geometry is known, and can be removed using the interferometric data itself [Rodriguez et al, 1999]. Detailed simulations using the TOPSAR data at degraded resolutions have shown that the main effect in this degradation in resolution is to increase the random noise in the height variance measurement. In order to obtain sensitivities similar to the ones shown above for TOPSAR, it is necessary to degrade the resolution of the estimated roughness to about 100m. This resolution is still sufficient for the applications in this proposal.

1.4 Calibration, Validation, Accuracy

In this proposal, the primary source of data for mapping the surface roughness length is the SRTM cross-correlation measurement from the interferometric SAR data. As described above, the algorithm is capable of measuring the surface roughness at a degraded resolution of 100 meter from each SRTM strip mode data. Although the 100 m resolution may be suitable for mesoscale studies (such as the proposed for model simulations), it will not be useful for regional and global scale modeling. Moreover, by degrading the resolution further to 1 km, by definition, we increase the accuracy of the surface roughness.

We propose to use VCL and airborne laser altimeter measurements to calibrate our algorithm for accurate measurement of roughness length over vegetated canopies. By collaborating with the VCL science team, we will use several along-track derived vegetation height measurements from the Lidar instrument as ground truth and calibration data for the SRTM based roughness estimation. For calibration and validation of our methodology, we propose to use data over the a limited sites in the Amazon basin where ground data will be collected during the LBA experiment. The processing of the VCL data will be according to its mission schedule and may not meet the schedule specific to this project. In the case of missing the opportunity of having VCL data over the Amazon basin, we may use any quick-look data released by the VCL processing team to perform the validation.

Furthermore, during the final development of the algorithm, we propose to also use current airborne data sets acquired by the JPL AIRSAR instrument and the laser altimeter over various vegetation types to enhance the accuracy of the parameter estimation. During the proposed work, we have the opportunity to acquire more simultaneous data of the two instruments over tropical forests during the Pacific Rim airborne campaign. We propose to use a well studied site in northern Queensland Australia for the Pacific Rim airborne campaign in the year 2000. Note that the proposed acquisition of airborne data will enhance the existing data sets from simultaneous measurements of IFSAR and Laser altimeter. However, the success of the proposed work does not depend on this new data acquisition.

In addition to VCL and airborne laser altimeter data, we propose to use ground measurements surface roughness. Currently, data from several large scale field campaigns are available in the literature, CD-ROMs, and web servers. Most measurements are accompanied by geographical position (GPS points) and some description of surface structure. In field experiments such as FIFE, BOREAS, HAPEX, and LBA, we also have access to aerodynamic roughness measurements. By collaborating with the scientist during the LBA experiment we will accumulate the ground data set required for validation and accuracy assessment of the roughness parameter map. The LBA experiment, in particular can provide a basin wide information of vegetation height variation for a variety of land cover types such as intact evergreen forest, dry forest, deciduous and semi-deciduous forest, secondary regeneration, floodplain forests, and areas undergone deforestation and cultivation. This ground data will be assembled by Dr. Denning group for both validation and accuracy assessment and development of a relationship between the aerodynamic roughness and physical roughness of the surface.

At the same time, by collaborating with modelers engaged in parameterizing the surface boundary layer for climate models over the LBA, we will be able to test how well the estimated roughness parameter will improve the model outputs. Since the development of the boundary layer models for the Amazon basin is already an integrated part of the LBA study, this collaboration (with Dr. Scott Denning and Carlos Nobre) will help to guide our research activity and at the same time to demonstrate the quantitative improvement of the modeling results using SRTM derived roughness map.

1.5. The Regional Atmospheric Modeling System – RAMS

RAMS is a general purpose atmospheric simulation modeling system consisting of equations of motion, heat, moisture, and continuity in a terrain-following coordinate system (Pielke *et al.* 1992). The model has flexible vertical and horizontal resolution and a large range of options that permit the selection of processes to be included (such as cloud physics, radiative transfer, subgrid diffusion, and convective parameterization). Two-way interactive grid nesting (Nicholls *et al.* 1995; Walko *et al.* 1995a) allows for a

wide range of motion scales to be modeled simultaneously and interactively. For example, with nesting, RAMS can feasibly model mesoscale circulations in a large domain where low resolution is adequate, and at the same time resolve the eddy fluxes caused by juxtaposition of different land cover types, such as occur when forest is adjacent to pasture land (Pielke *et al.* 1992).

Several major RAMS developments were completed in the last few years which greatly enhance its ability to simulate the components of the hydrological cycle. The RAMS system has already been in use by Brazilian investigators for a number of years (e.g., Rocha *et al.*, 1996). During the LBA 4DDA program, model simulations of atmospheric circulations will be performed by using the nested grid feature of RAMS. Weather data will be assimilated on a grid of order 10's of km, and 6 levels of nested fine scale grids will be used to produce simulations of the atmospheric circulation down to the scale of a large eddy simulation (LES) in the immediate vicinity of the flux towers chosen for this study (order a few 10's of meters).

RAMS has a built-in interface to the ARC-Info Geographic Information System, which will facilitate the incorporation of other LBA data sets (MODIS imagery, topographic and hydrologic data for boundary conditions, etc) into the coupled simulations of carbon and isotope exchange with SiB2. The modeling system includes code for simulating the trace gas transport and concentration and investigating interactions between CO₂ concentration in the canopy air space and the physiological function of the forest. We will perform prognostic simulation of within-canopy concentration and isotopic composition of CO₂. For the regional simulations proposed later in the study, we will also include parameterized transport by PBL turbulence and deep convection, which will be impossible to resolve at the basin scale.

***** RAMS model is suitable to demonstrate the effect of the roughness parameter derived from this project on the simulation of trace gas transport both at a local level for the LBA study areas and at the regional scale for the entire Amazon basin. ***** The parameter map generated from the SRTM data will be included in the built-in GIS interface of RAMS model for the parameterization of boundary layer. The comparison of model simulation with the aerodynamic roughness length derived from SRTM and from the lookup table will enable us to quantify the improvement of simulations in terms of the

changes in model outputs. Dr. Scott Denning agreed to perform the model simulations at 1km scale for the regional study and at 100 m scale for local study as part of his LBA modeling proposal.

2. Relevance of Proposed Work

The proposed effort will provide one of the most important parameters for global climate models and land cover change studies. In addition, the work combines the SRTM data with other remote sensing missions such as VCL to establish a data fusion approach for retrieving structural parameters of land surface. SRTM estimation of topographical altitude is modulated with the vegetation height over forest cover types and the VCL estimation of vegetation height is modulated by the surface topography. This effort, therefore, will help to establish a synergistic method for possibly removing the vegetation and topography effects in both data sets in future.

The results from the proposed research will provide a benchmark data of surface roughness for understanding the effect of surface variability in GCM models. It will demonstrate the scientific use of the SRTM data and the relevance of its integration with large scale analysis of atmospheric boundary layer problems. It will provide an important contribution for validating modeling efforts, and our understanding of land degradation and changes of biotic carbon stock. The work also addresses topics of SRTM radar phenomenology and development of new operational algorithms for future missions, such as LIGHTSAR, that provide interferometric SAR data for characterizing the surface change and vegetation structure.

3. Expected Results

The result expected from the proposed work is a 1 km resolution global map of the surface roughness over the coverage area of the SRTM data between 60° N and 57° S with centimeter accuracy. This is our only objective. However, the process of producing this parameter map, will allow us to provide the following secondary results:

1. A calibration and validation data set for both SRTM and VCL missions. This data set will include a suite of registered VCL along-track 25 m footprint laser altimeter data and SRTM strip data with 30 m spacing over various land cover types.

2. A validation data set of surface aerodynamic roughness length extracted from the existing measurements published in literature or available from the archive of large scale field experiments such as FIFE, BOREAS, HAPEX, and LBA.
3. High resolution roughness and vegetation height maps (100 meter) from SRTM and VCL data over the LBA intensive study areas for the local to regional scale modeling experiments.
4. An operational algorithm for estimating surface roughness parameter for future missions such as LIGHTSAR and a set of recommendations and guidelines for monitoring the changes of surface roughness. We will report our results in open literature and provide the parameter map on NASA and JPL web sites.
5. A simulation result from an atmospheric boundary layer model over the LBA study area using the SRTM derived roughness parameter and an assessment of the improvement of the model output as a result of the new parameter map.

4. Detailed Work Plan

Year 1

During the first year, we propose to upgrade the algorithm for estimating the surface roughness from the SRTM data. The algorithm has been applied to the interferometric SAR data obtained by the AIRSAR system. The improvement of the estimation algorithm can be done at the following stages:

1. To simulate the IFSAR data for various vegetation cover types by coupling a physically based model developed by Rodriguez et al., (1998) and Saatchi et al., (1997) and at the same time using the AIRSAR data acquired during the first Pacific Rim deployment. The model simulation and its application on real data can improve the implementation of algorithm on SRTM data by understanding the behavior of signal

characteristics from various land cover types. In addition, the algorithm will be modified to use both the H and V polarization interferometric data obtained by SRTM.

2. We will assemble existing ground data collected over several field campaigns such as BOREAS, FIFE, HAPEX, and other ground measurements reported in literature including their geographical locations. Meanwhile we will work closely with the LBA science team by collaborating with Dr. Carlos Nobre and Dr. Scott Denning to make sure that a reliable ground data representative of various land cover types, land use scenarios, and geographical locations are collected over the LBA study areas.

3. We will test the performance of the algorithm by using data over BOREAS study areas acquired in 1995 and the Pacific Rim campaign in 1998.

4. We will assemble a series of simultaneously acquired data from laser altimeters such as the Goddard Space Flight Center Scanning Lidar Imager of Canopies by Echo Recovery (SLICER), and the shuttle laser altimeter (SLA) and the AIRSAR/TOPSAR data. We propose to acquire the cloud free SLA data over sites in Australia where we have and will collect AIRSAR data. The SLA track over Australia covers a region where we have already established collaborative relation with scientists for ground data collection (personal communication with Tony Milne).

Year 2

We hope to access the first strips of SRTM and VCL data over some of the intensive study areas of the LBA experiment. We will register the VCL data with the SRTM interferometric cross-correlation data and develop a data set for calibration and validation of the roughness estimation algorithm. During this year we will coordinate our efforts with the VCL team by collaborating with Dr. Ralph Dubayah (the VCL mission principal investigator) to make sure that the quick-look VCL strip is processed. In case of any schedule conflict with the VCL data processing requirement we will either postpone this portion of the proposed work for the third year or use any quick-look VCL data that overlap with the first SRTM processed data.

The entire procedure of estimating the surface roughness parameter over the overlapping strip of SRTM and VCL, calibration of SRTM algorithm with VCL height information, validation of results, and resampling to 1 km resolutions will be performed during this year. We also hope to acquire ground data over the LBA sites for comparison with the estimated roughness parameter and assessment of the accuracy.

In addition, we will process a new set of simultaneous data of airborne laser altimeter and AIRSAR interferometric data over a selected site within the area covered during Pacific Rim II campaign. This campaign will provide additional data for simulating the SRTM and VCL data and will allow the fusion of the two data sets for the topography and vegetation height correction.

During this year, our team at JPL will start processing the data acquired by the Shuttle and produce cross-correlation images to be used in parameter estimation. The processing of entire SRTM orbital data will be time consuming and will continue during the third year of the proposal. We intend to integrate the algorithm in the processing chain and directly produce parameter maps. These maps will be generated at 1 km scale in order to reduce the disk space for storage. Currently a mosaicking software has been developed for the SRTM project for producing seamless global topography images. The same software can be used to generate the mosaic of roughness parameter at 1 km resolution.

We will also perform a literature survey and assemble a database of ground measurements of aerodynamic roughness and vegetation characteristics and geographical locations from field experiments. This database will be used to examine the one-to-one relationship between physical and aerodynamic roughness parameters as well as for validation.

Year 3

We propose to finalize the results of our work during the third year of proposal when all data from SRTM mission are processed. This process includes the production of a wall to wall mosaic image of the aerodynamic roughness at 1 km resolution derived from SRTM data. The entire parameter map will be validated with data acquired from VCL and its accuracy will be assessed quantitatively. We will report the validation results

over various geographical locations and land cover types. We will use the existing 1 km global vegetation map derived from the AVHRR data to demonstrate the distribution of roughness parameter over land cover types.

At this phase of the proposed work, the parameter map will be ready to be used in GCM type model developed by our co-investigators to assess the contribution of the parameter map in improving the results from these model.

This work will require close interaction with co-investigators from the VCL science team and the modeling team. When possible, we will participate in LBA science team meetings to coordinate the modeling and the ground data collection over the Amazon basin. Funds for ground data collection and model simulations are available already under separate grants from LBA project. The results from proposed research will be reported in publications in open literature and will be available from the JPL and NASA web sites.

5. Role of PI, CO-I, and Collaborators

The proposal involves collaboration among participants at the University of Maryland and VCL processing team, Colorado State University, LBA science team at INPE , and the Jet Propulsion Laboratory, each with unique resources and capabilities.

At the Jet Propulsion Laboratory, the principal investigator (Saatchi) will have the overall responsibility for the project, testing and improvement of the retrieval algorithm for the SRTM data, analysis and validation of results in collaboration with other colleagues, and production of wall-to-wall 1 km scale map of aerodynamic roughness over the entire surface area covered by SRTM, production of maps at 1 km scale for the LBA regional study area and 100 m maps for the local intensive study areas.

The co-investigators at JPL (Rodriguez and Simard) will be involved in testing and improvement of algorithm on the airborne data, comparison and calibration of algorithm with the laser altimeter data, and application of the algorithm on the SRTM data. Moreover, Dr. Rodriguez will be responsible to coordinate the processing of the SRTM data for this project at JPL. The data acquired from the JPL SRTM processed will

be post-processed to generate the required cross-correlation data needed for roughness parameter estimation.

The University of Maryland (Dubayah) as a co-investigator of this project and the principal investigator of the VCL mission will be responsible for the processing and delivery of quick-look VCL data over LBA sites for calibration and validation of the SRTM derived parameter. In addition, Dr. Dubayah and his student will participate in analyzing the airborne laser altimeter and interferometric SAR data over test sites, and will be involved in calibration and validation of SRTM data for roughness estimation.

The State University of Colorado at Fort Collins, Department of Atmospheric Studies (Denning) as a co-investigator will be responsible for assembling the ground data available in the literature or from various field experiment data archives for validation. Dr. Denning will be performing the model simulation over the entire Amazon region and in intensive study areas by using the derived roughness parameter and assessing the contribution of the SRTM derived parameter map on model outputs.

The CPTEC and INPE, Brazil (Nobre) is the coordinator of LBA scientific activities in Brazil and will provide the ground data collected during the LBA experiment to this project. Due to his responsibilities in LBA project, Dr. Nobre will participate only as a collaborator in order to coordinate our ground data collection and modeling activity with the LBA scientists.

6. Data Requirement and Processing

The key SRTM measurement for the techniques proposed here is the interferometric correlation, which is not one of the standard data products to be generated by SRTM. However, one of us (Rodriguez) is currently funded by NIMA to study the use of SRTM data for the generation of land use classes. As part of this effort, NIMA has consented to provide the funds necessary for the archiving of the geolocated interferometric correlation data for each of the SRTM subswaths. The data volume for

this data set is approximately 1.6 Terabytes, and covers the Earth between 60° N and 57° S latitude approximately twice at a resolution of about 30 m.

We propose to coordinate with the SRTM Ground Data Processing System (GDPS) and other tasks at JPL using this data set (such as the terrain classification), to design an in-line aerodynamic roughness estimation processor to process, mosaic and geolocate the data to produce a 1km resolution global (between 60° N and 57° S latitude) aerodynamic roughness map. Assuming data averaging and mosaicking to the 1 km resolution level, the total output data volume is approximately only 1GB, which can easily be stored given current storage capabilities. The processing will occur at 30m resolution (to remove geometric effects), with buffering at the subswath level. Each SRTM subswath covers an area of approximately 500km x 50km, for a total data volume of about 1Gbyte for all the data required for the processing, which again is quite manageable. The speed of the current scatterer variance algorithm is on the order of 4,000,000 Pixels/minute on an SGI R1000 Octane. Taking into account overheads for data transfers, dead-reckoning mosaicking of the output data, and ancillary data processing with a 30% safety margin and assuming 12 hour processing time, this results in a total processing time of about 360 days, which is within the budget and timeline of the current proposal.

The VCL along-track data over LBA sites will be processed at the University of Maryland after the launch of the mission in order to provide baseline data for calibration and validation of the SRTM retrieved roughness parameter.

Airborne AIRSAR interferometry data at C-band and SLICER laser altimeter data over test sites will be processed at JPL and University of Maryland respectively. We intend to use existing data sets with the addition of a site during the Pacific Rim II campaign. A separate proposal will be submitted to acquire data from both instruments.

Ground data from various field experiments such as FIFE, BOREAS, HAPEX, LBA, and from the literature will be assembled at the Colorado State University. This data will be provided to the project at the end of the year 2 of the proposed work in order to be integrated in the calibration and validation of the algorithm.

7. Supporting Facility

The Jet Propulsion Laboratory has adequate computer and other facilities for carrying out its portion of the project. The SRTM data processing team at JPL has its own dedicated computer and manpower. Additional computer and manpower will be dedicated to this project for a timely processing of data used in this project and mosaicking of the parameter map. We propose to purchase a 36 Gbyte disk space to be used on the dedicated workstation for SRTM data processing and storage.

Similarly, the University of Maryland, and Colorado State University have adequate computer and other facilities for carrying out their portion of the project.

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Figures:

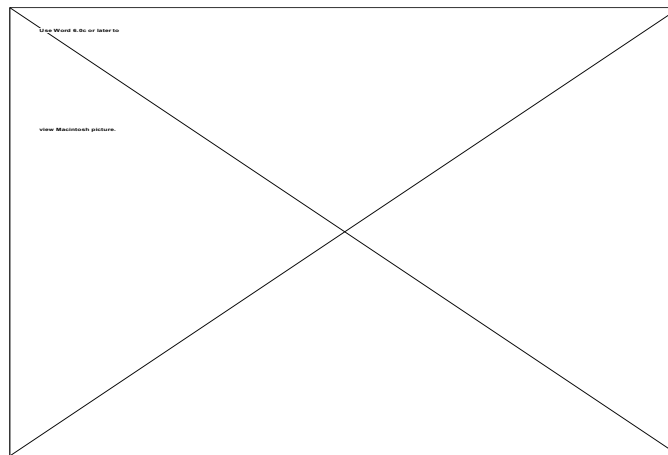


Figure 1. SRTM Radar data coverage at 30 meter horizontal resolution.

Figure 2. Measured heights for the laser measured tree canopy top (solid line), ground height (dotted line), and IFSAR measured mean height (dashed line). Figure (a) shows

the results for the old growth/clear cut area near Wallupt Lake. Figure (b) shows the results on the flank of Mt. Adamas and near Potato Hill.

Figure 3. Comparison of the laser estimated scatterer dispersion, or height variation (solid line), to the IFSAR derived scatterer dispersion (triangles). The results cover old growth, regrowth areas, and clear cuts. No scaling has been applied to either the laser or IFSAR data.

9. Resume, Current and Pending Support

10. Budgetary Information and Explanations

The proposal is being submitted by JPL and the required budget includes funding for part time students at University of Maryland and the Colorado State University to carry out various portions of the proposed work.