1. Introduction

A major goal of DESDynI is to produce a grid of estimated above ground biomass (EAGB) at fine spatial resolution by the end of mission life (5 years). Quantifying the dynamics of forest biomass changes is critical for determining the flux of carbon between the land surface and atmosphere caused by deforestation, degradation, and subsequent recovery. The basis of these dynamics rests on the ability of DESDynI to accurately measure EAGB on a yearly basis. DESDynI's approach is to develop strategies that efficiently use the fusion of radar and lidar to estimate the full range of biomass down to a spatial resolution of 250 m. In this paper we outline proposed methodologies for EAGB. Our paper is organized as follows. First we list mission requirements for biomass accuracies and briefly describe their underlying science drivers. Next we discuss the anticipated approaches for deriving EAGB using lidar alone and radar alone. We then examine potential fusion approaches and explore where they are likely to be needed. Lastly, we provide sensitivity analyses that demonstrate the efficacy of proposed methodoliges in terms of meeting the quantitative mission requirements of DESDynI.

2. DESDynI Biomass Requirements

The overall science goal of DESDynI is to characterize the effects of changing climate and land use on the terrestrial carbon cycle, atmospheric CO_2 and species habitats. Central to this goal is the first science objective of DESDynI which is to provide spatially explicit and consistent global distribution of EAGB. Uncertainty in the spatial distribution of biomass accounts for at least half of the uncertainty in estimates of the net flux of carbon from land-use change (Houghton 2005).

The spatial variability of biomass is patchy, and varies rapidly in space as a result of changes in disturbance patterns, and local edaphic and climate regimes. It is thus important to characterize biomass at the same scales at which this variability manifests. Most disturbances (and thus regrowth) occur at around the one hectare scale. Thus it is imperative that DESDynI map biomass at scales considerably below and with far greater accuracy than currently possible. Reflecting this, the mission requirement associated with the biomass science objective is:

> The DESDynI Mission shall map aboveground woody biomass within the greater of 20 Mg/ha or 20% (errors not to exceed 50 Mg/ha), at a spatial resolution of 250 m globally and 100 m for areas of low biomass annually (< 100 Mg/ha).

The DESDynI accuracy requirementt are based on our best understanding of the improvement required to significantly reduce this uncertainty. While the goal of DESDynI is to map EAGB everywhere at this resolution, this may not be possible, even with fusion, given the known limitations of radar and spatial incomplete sampling of lidar as discussed below.

3. DESDynI Approaches to Biomass Estimation

DESDynI consists of an L-band polarimetric interferrometric SAR and a multi-beam lidar. The radar will completely image the Earth every 8 days with a native pixel resolution of about 20 m. The lidar is comprised of 5 beams, separated across track by 1 km, and contiguous along track. This produces a pattern of 5 transects, each comprised of contiguous footprints 25 m in diameter, each of which produces a full waveform that gives the distribution of vertical reflective surfaces in 30 cm increments. At the end of mission, tracks will be separated by 250 m. This will provide about 50 cloud-free observations per 500 m grid cell at the equator, which increasing observations as latitude increases.

Each instrument is capable of producing estimates of biomass but each has its limitations. While the radar is spatially complete studies to date have not demonstrated effectiveness at biomass levels above 100 Mg/ha. Lidar has shown no such saturation effects, but is not spatially complete. Thus, a core methodological objective is to devise fusion strategies that enable estimates at the required spatial resolution of 250 m.

Note that for both radar and lidar it is assumed that by the time of DESDynI launch a global network of ground plot locations and associated accurate allometry will be available to enable the development of statistically stable and accurate relationships for deriving EAGB using field data.

3.1 Lidar-derived Biomass

The DESDynI approach to derivation of EAGB using lidar is based on statistically relating waveform metrics, such as height and energy quantiles to field based estimates of biomass. Past studies have shown lidar can meet the DESDynI requirements for accuracy at the plot level. However, because DESDynI uses a sampling lidar, in addition to statistically- based errors there are also sampling errors. Research has shown that DESDynI lidar by itself cannot meet accuracy goals at 250 m in equatorial regions across all biomass ranges because of sampling limitations. Only when the resolution is increased to 500 m and beyond are enough samples available to sufficiently reduce sampling error.

3.2 Radar-derived Biomass

DESDynI will use polarimetric radar backscatter to statistically predict biomass. Most radar studies show decreasing accuracy beyond 100 Mg/ha, reaching a saturation quickly after this point. By itself DESDynI radar meets requirements for low biomass areas at a spatial scale of 1 ha. This is achieived in a given season by multiple looks at the same location (up to one every 8 days) that can be used to statistically beat down biomass uncertainty. For areas over 100 Mg/ha, DESDynI must rely on lidar by itself (with coarser spatial resolution) or by combing the radar and lidar observations in fusion approaches, discussed next.

4. Fusion Approaches

The basic methodology for producing an annual biomass map is comprised of combining lidar and radar estimates of biomass at differing spatial resolutions and accuracies to make estimates on a variable resolution map. As more lidar samples are added through the mission the grid resolution is reduced. Using only this approach would result in a map at the end of the mission of 250 m resolution where low biomass areas meet spec, but some areas do not as a function of latitude, cloud-cover and biomass magnitude. Thus, some type of fusion approach beyond this is needed. Preliminary studies suggest that using advanced statistical techniques, such as decisions trees or maximum entropy, sparse lidar data may be combined with radar to greatly extend the range of biomass where they are viable. A variant of this approach is to use the texture information available from radar (and other ancillary data) to stratify the landscape into polygons of similar structural attributes. Lidar data where it is available is used to map patch level biomass, and other patches for which lidar data are absent are inferred .

A second approach to fusion is based on physical modeling, where information on canopy structure is used to parameterize or otherwise constrain, radar inversion models of canopy structure. For example, lidar could be used to obtain the profile of foliar leaf density (in m^2/m^3). This could then be used to infer canopy structure (such as height) which in turn could be related to biomass).

Lastly, the ability of DESDynI to perform SAR interferrometry may be exploited. While algorithms for deriving height from InSAR are in their infancy, a global network of billions of height observations from the DESDynI lidar offers great promise that either statistical or physically-based methodologies may be developed to enable the derivation so canopy structure and biomass.

5. Conclusion

Biomass will be a key environmental variable for predicting the effects of natural and anthropogenic disturbances for a variety of issues, from predicting atmospheric carbon dioxide concentrations to explaining patterns of biodiversity and habitat suitability. DESDynI will provide EAGB at unprecedented spatial scales and accuracies using proven techniques. With the development of advanced radar/lidar fusion techniques and the tantalizing possibility of direct retrievals of forest structure through insar/lidar fusion, DESDynI may likely go far beyond its requirements to provide data truly revolutionary in its depth, scope, and accuracy.