BigFoot: A Project Linking *In-situ* and Satellite Measurements to Validate MODIS Terrestrial Ecology Products

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OVERVIEW

MODIS is the principal high temporal frequency mapping sensor on-board Terra, NASA's flagship Earth Observation System. Using MODIS data, the MODIS Land Discipline Group (MODLand) is developing a series of global map products that will play an important role in monitoring the Earth as a system. However, as these products are developed using coarse resolution data, generalized algorithms, and without reference to ground data, their validation is crucial to establish their accuracy for the scientific user community, and to provide feedback for improving the MODLand data processing algorithms. The BigFoot Project was initiated to address these validation issues for four primary terrestrial ecology products: land cover, the absorbed fraction of photosynthetically active radiation (FPAR), leaf area index (LAI), and net primary production (NPP).

There are four BigFoot study sites: the BOREAS Northern Old Black Spruce site in No. Manitoba; The Konza Prairie Research Natural Area in Kansas; Harvard Forest in Massachusetts; and a group of agricultural farmlands in Illinois. BigFoot field sites have active science programs concentrating on CO_2, water vapor, and energy exchange using eddy covariance flux tower measurements, which have a Afootprint@ of roughly 1 km^2 . BigFoot will provide spatial context for the tower measurements by studying processes over a 25 km^2 area at each site, hence the project=s name.

VALIDATION METHODS

For each 25 km^2 site BigFoot creates land cover, LAI, FPAR, and NPP surfaces from the combination of field data, Landsat ETM+ imagery, ancillary data, and a variety of algorithms based on statistical, geostatistical, radiative transfer, neural-net, and ecosystem process models. The primary objective in creating these layers is to develop highly accurate maps that can serve as "truth" in comparisons with MODLand data layers having similar themes. BigFoot data layers have a resolution of 25 m and are based on site-specific algorithms to capture scales of processes that are functionally important at the local level. Each data layer is compared with independent field measurements to characterize errors.

For all BigFoot sites the field sampling design is a nested approach that provides a greater number of sample locations for easily measured characteristics (i.e., vegetation cover, aboveground biomass, LAI, and FPAR) and fewer sample locations for more laborious measurements (i.e., above and below ground net primary production). Using any easily measured vegetation characteristic, a correlogram (a plot of autocorrelation coefficient values versus distance), is constructed to determine autocorrelation intensity, the size of the zone of influence, and the type of spatial pattern. The shape of the correlogram provides insight into spatial pattern and underlying processes that influence the vegetation characteristic of interest. The 25 m plot is the experimental unit in that each plot produces only one value for each parameter measured; however, multiple sub-plots are used to characterize each plot.

Field methods vary by plant type. LAI is measured using both direct (i.e., harvest, allometry) and indirect (i.e., optical) techniques. The indirect method is based on, and thus yields, FPAR. Aboveground NPP is measured separately for each plant species and major vegetation component (e.g., woody, foliage) using harvest and allometric methods. Belowground NPP is measured using minirhizotrons (for fine roots) and allometrically (for coarse roots). Specific leaf area and leaf nitrogen are measured for each major plant species. Each plot is remeasured 4-7 times during the growing season and each site is visited for measurements two consecutive years to capture interannual variation. For land cover mapping, at some sites, special attention is required to quantify how vegetation cover component proportions vary across a range of scales. To quantify overstory and understory cover component proportions we developed the Vegetation Cover Component Characterization System, consisting of a tripod that holds two digital cameras on a horizontal extension crossbar, with one camera facing up and one facing down. The ground area imaged is approximately 1.5 m by 0.75 m. The imaged canopy projection area is dependent on tree height. In the lab, the photos are sampled using a grid of 99 points.

The objective of BigFoot land cover mapping activity is to develop high-quality data layers that contain basic building blocks for numerous land cover classification schemes. To accomplish this we will map fundamental vegetation and related properties such as fractions of photosynthetic and non-photosynthetic vegetation, soil, and shadow. For these fractions, we will distinguish among overstory and understory vegetation components, as well as ground cover. For woody vegetation, we will distinguish shrublands from woodlands and forests, as well as evergreen needleleaved, evergreen broadleaved, deciduous needleleaved, and deciduous broadleaved components. Additionally, for forests, we will model a variable related to age or structure. Grasslands will be distinguished from croplands, and to the extent possible, we will map fractions of specific types within these broad categories. Other fractional components of importance that we will identify are water, urban, and similar land features. Wherever possible, we will maintain continuous estimates of each land cover component or property to insure compatibility with other land cover mapping schemes. A combination of methods and data will be used to develop BigFoot land cover surfaces, including supervised and unsupervised classification, regression and mixture modeling, and a neural network.

LAI and FPAR surfaces will be derived from regression models based on spectral vegetation indices, radiative transfer modeling, and geostatistics. We will test two geostatistical methods for mapping LAI and FPAR: co-kriging and conditional simulation. Kriging, in its basic form, is an optimal, unbiased linear technique for estimation. Co-kriging is the extension of kriging to multiple variables that takes advantage of the relationship between high quality, undersampled field-based measures (e.g., LAI, cover) and an associated lesser quality, but more spatially extensive set of secondary variables (e.g., image data). Although conditional simulation (which has several variants) is similar to co-kriging, there are some important differences. Co-kriging produces a single map with minimum variance from expected truth on a pixel-by-pixel basis, but the spatial pattern is compromised (smoothed). Conditional simulation results in several equally probable maps, but in each map the true spatial pattern is retained and global (rather than pixel-by-pixel) variance is minimized. Additionally, because conditional simulation incorporates a probabilistic function, uncertainty in the spatial distribution of the mapped variable can be characterized.

Surfaces of net primary production will be generated using two spatially-distributed ecosystem process models: PnET and Biome-BGC. The most critical spatially varying model inputs are BigFoot land cover and LAI surfaces and soil water holding capacity (WHC). LAI will be used to derive maximum fine root biomass and sapwood biomass (in the case of forests) using allometric relationships. Seasonal trends in LAI and fine root biomass will be determined by the phenology component of the models. For WHC, an initial average value for each site will be obtained from the WHC surface generated by the VEMAP project. Where local digital maps of soil texture and depth to bedrock are available at a finer spatial resolution, this information will be used to create an alternative water holding capacity surface. The daily climate variables to drive the models will be maximum temperature, minimum temperature, solar radiation (total short-wave and photosynthetically active), precipitation, and daytime average vapor pressure. The meteorological data to generate these climate surfaces will be based on measurements at the flux towers.

To "validate" the four MODLand terrestrial ecology products of interest, BigFoot and MODLand data layers will be compared. Comparisons include site-level statistical summaries, as well as direct cell-by-cell overlays to evaluate effects of fine-grained heterogeneity on MODLand characterizations.

SCALING EXERCISES

In addition to MODIS validation, BigFoot objectives include exploring errors and information losses that accrue with increasing generalization when modeling NPP. The intent is to gain knowledge about scaling that can assist MODLand and other science teams modeling ecological processes at regional to global scales. To this end, our site-specific surfaces for each variable are generalized in a number of ways, NPP modeling is repeated, and the new NPP surfaces are compared against the original, site-specific Atruth@ NPP surfaces.

Generalization takes two forms: spatial and informational. Spatial generalization involves degrading the grain size of the original ETM+ imagery to 100 m, 250 m, 500 m, and 1 km resolution and then using the site specific algorithms to develop new surfaces. Generalizing in the informational domain is limited to land cover, where site-specific functionality of land cover information is compromised by translating that information into generalized classes used by MODLand and other global modelers, such as the IGBP classification scheme.

SUMMARY

The primary aim of the BigFoot project is to develop high resolution gridded surfaces of land cover, LAI, FPAR, and NPP that can be compared to corresponding MODIS products. Additionally, we are taking the opportunity to: a) explore errors and information losses that accrue when extrapolating field data to coarse grain (1 km) surfaces; b) determine if there is a fundamental grain size at each site, above which error rates accelerate when modeling land cover, LAI, FPAR, and NPP; c) develop a better understanding of the climatic and ecological controls on net primary production and carbon allo cation within and among biomes; and d) learn how flux tower measurements of net ecosystem exchange and field measurements of NPP co-vary, and how to translate between them using ecological models.

For references and additional project information please visit our website (http://www.fsl.orst.edu/larse/bigfoot) and see our special issue of *Remote Sensing of Environment* (Vol. 70, No. 1, 1999).