

Biomass estimation based on simultaneous use of standwise forest inventory data, ASTER and MODIS satellite data

P. Muukkonen, Finnish Forest Research Institute, P.O. Box 18, FI-01301 Vantaa

J. Heiskanen, Department of Geography, University of Helsinki, P.O. Box 44
FI-00014 University of Helsinki

According to the Intergovernmental Panel on Climate Change Good Practice Guidance (IPCC GPG) (IPCC 2003), remote sensing methods are especially suitable for independent verifying the national Land Use, Land-Use Change, and Forestry (LULUCF) carbon pool estimates, especially the aboveground biomass. In the present study, we demonstrate the potential to integrate standwise inventory data, ASTER and MODIS satellite data for characterizing stand volume ($\text{m}^3 \text{ha}^{-1}$) and aboveground biomass of trees (t ha^{-1}) in boreal forests landscape in the southern Finland. The simultaneous use of high and coarse resolution images is essential especially when estimating these forest characteristics for extensive areas where ground data are not available or are limited. In this study, the regression models computed using standwise forest inventory data and ASTER satellite images were utilized with the MODIS data.

ASTER is a high spatial resolution multispectral imager with three subsystems operating in different spectral regions, namely the visible and near infrared (VNIR), the shortwave infrared (SWIR), and the thermal infrared (TIR) (Yamaguchi et al. 1998). The spatial resolution is 15, 30 and 90 m for VNIR, SWIR, and TIR, respectively. A single ASTER image covers an area of $60 \times 60 \text{ km}^2$. MODIS have four refractive objective assemblies; one for each of the visible (VIS), the near infrared (NIR), the shortwave and midwave infrared (SWIR/MWIR) and the longwave infrared (LWIR) spectral regions (Ardanuy et al. 1991). Two bands are imaged at a nominal resolution of 250 m at nadir (bands 1–2), with five bands at 500 m (bands 3–7), and the remaining 29 bands at 1 km (bands 8–36). Swath dimensions are 2330 km (across track) by 10 km (along track at nadir). These both imager instruments, ASTER and MODIS, were carried onboard spacecraft Terra (Earth Observing System AM) on December 18, 1999. MODIS spectral bands 1 and 2 covering the same wavelength area than ASTER bands 2 and 3 were calibrated using linear regression analysis (Häme et al. 1997).

In the work of Muukkonen and Heiskanen (2005), the ASTER remote sensing data were analysed and tested together with standwise forest inventory data. The locational problems of plot-level ground reference data were solved by employing the forest stand data instead of the plot-level data (Mäkelä and Pekkarinen 2004). Stand volume estimates of standwise data were converted to aboveground tree biomass using biomass expansion factors (Lehtonen et al. 2004), and the aboveground biomass of understory vegetation was predicted according to the stand age (Muukkonen and Mäkipää 2006). Non-linear regression analysis and neural networks were applied to develop models for predicting biomass according to standwise ASTER reflectance. All ASTER bands appeared to be sensitive to tree biomass, in particular the green band 1. The relative estimation errors (RMSE_r) of the total aboveground biomass of the forest stands were 44.7% and 41.0% using multiple regression analysis and neural networks, respectively. Although the estimation errors remained large, the predictions were relatively accurate in comparison to previous studies.

After applying the regression models based on ASTER data to MODIS data (Muukkonen and Heiskanen 2006), predicted stand volume compared according to the national forest inventory estimates (NFI) for Finnish Forestry Centres (Figure 1). The Finnish Forestry Centre network consists of thirteen regional Forestry Centres. The predictions obtained here were significantly close

to the district-level mean values provided by the National Forest Inventory of Finland. When comparing our stand volume predictions to field survey based National Forest Inventory (NFI) estimates, the relative RMSE and bias for whole study area were 8.3% and 2.4%, respectively. The stand volume was used as a halfway step to estimate the aboveground biomass of trees and the aboveground biomass of all vegetation since it is commonly measured on the ground, but which is also very closely related to biomass (Häme et al. 1997). The stand volume was converted to aboveground biomass of trees and to aboveground biomass all vegetation using regression models developed by Häme et al. (1997).

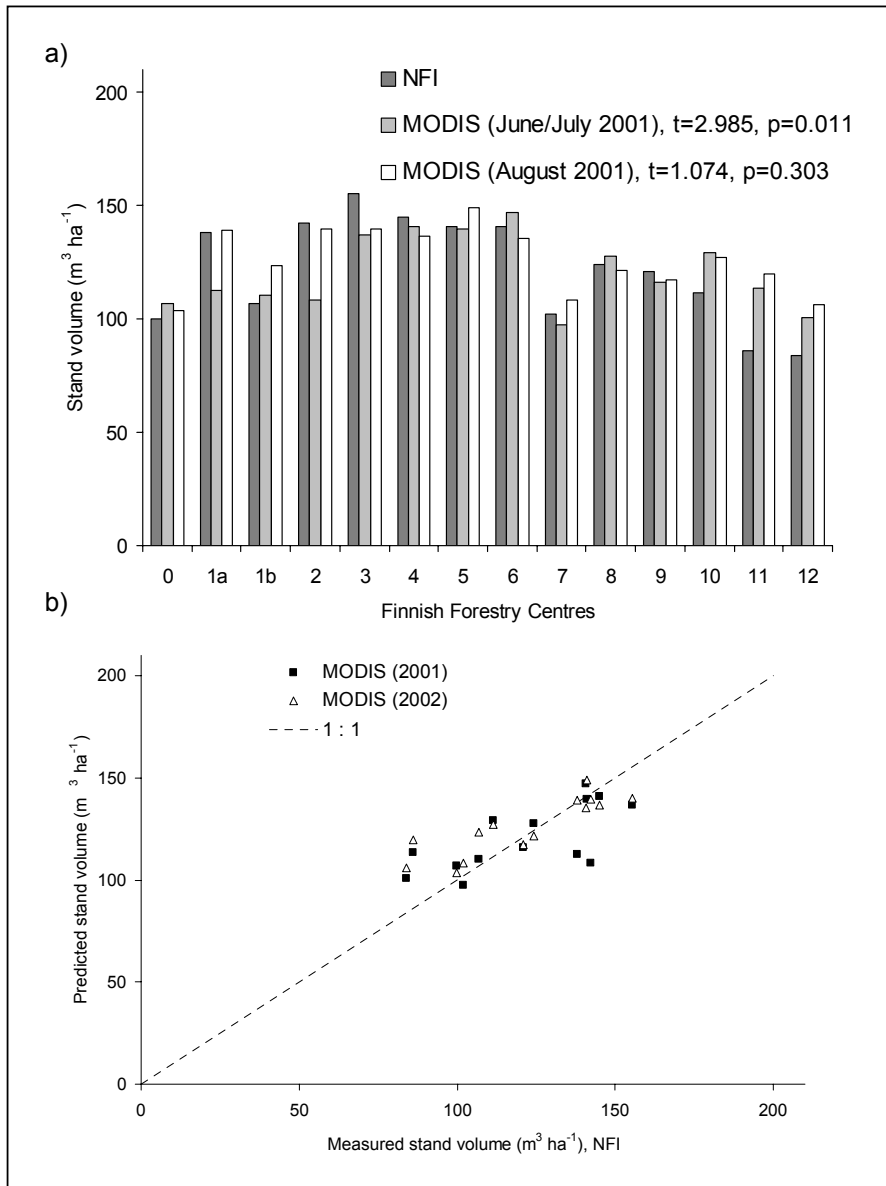


Figure 1. Comparison of modeled and measured stand volume (NFI).

Our average aboveground tree biomass estimates ($59.3\text{--}64.9\text{ t ha}^{-1}$) for the Forestry District "Rannikon metsäkeskus / Pohjanmaa" are rather close to previous estimates of Tomppo et al. (2002), $58.3\text{--}59.5\text{ t ha}^{-1}$. In addition, our average estimates of aboveground tree biomass and aboveground biomass of all vegetation for the entire study area (southern Finland) are quite close to inventory based estimates of Liski et al. (2005) (see Table 1).

Table 1. Predicted and measured aboveground biomass for southern Finland

	Aboveground tree biomass (t ha ⁻¹)	Aboveground biomass of all vegetation (t ha ⁻¹)
MODIS(June/July2001)	65.4	69.9
MODIS(August2001)	68.8	73.2
Liski et al. (2005)	67.6	70.9

The method illustrated together in the studies of Muukkonen and Heiskanen (2005, 2006) can be used for predicting the mean stand tree (e.g. m³ ha⁻¹) and the mean stand biomass (e.g. t ha⁻¹), since this method provides adequate prediction of these variables. The method described in this study can therefore be used as required independent verification data. Our results show that high resolution (15 m × 15 m) ASTER data can be used as an intermediate step between ground reference data and coarse resolution (250 m × 250 m) MODIS data. Although the coefficient of determination values were low in the models derived from the ASTER data, the MODIS stand volume estimates for the Forestry Centre level were quite satisfactory. While the MODIS data are useful for regional assessments of stand volume and aboveground biomass, our results suggest that data with both higher spatial and temporal resolution will be required to address biomass estimates.

References:

- Ardanuy, P.E., Han, D. & Salomonson, V.V. 1991. The Moderate Resolution Imaging Spectrometer (MODIS) science and data system requirements. *IEEE Transactions on Geoscience and Remote Sensing* 29(1): 75-88.
- Häme, T., Salli, A., Andersson, K. & Lohi, A. 1997. A new methodology for estimation of biomass of conifer-dominated boreal forest using NOAA AVHRR data. *International Journal of Remote Sensing* 18(15): 3211-3243.
- IPCC 2003. Good Practice Guidance for Land Use, Land-Use Change and Forestry. IPCC National Greenhouse Gas Inventories Programme, Hayama, Japan. 295 p.
- Lehtonen, A., Mäkipää, R., Heikkinen, J., Sievänen, R. & Liski, J. 2004. Biomass expansion factors (BEFs) for Scots pine, Norway spruce and birch according to stand age for boreal forests. *Forest Ecology and Management* 188: 211-224.
- Liski, J., Lehtonen, A., Palosuo, T., Peltoniemi, M., Eggers, T., Muukkonen, P. & Mäkipää, R. 2005. Carbon sink of the Finnish forests 1922-2004 estimated by combining forest inventory data with modeling of biomass, litter and soil. Submitted manuscript.
- Mäkelä, H. & Pekkarinen, A. 2004. Estimation of forest stand volumes by Landsat TM imagery and stand-level field-inventory data. *Forest Ecology and Management* 196: 245-255.
- Muukkonen, P. & Heiskanen, J. 2005. Estimating biomass for boreal forests using ASTER satellite data combined with standwise forest inventory data. *Remote Sensing of Environment* 99(4): 434-447.
- 2006. Biomass estimation based on simultaneous use of standwise forest inventory data, ASTER and MODIS satellite data. Submitted manuscript.
- Muukkonen, P. & Mäkipää, R. 2006. Biomass models of understorey vegetation according to site attributes in boreal forests. Submitted manuscript.
- Tomppo, E., Nilsson, M., Rosengren, M., Aalto, P. & Kennedy, P. 2002. Simultaneous use of Landsat-TM and IRS-1c WiFS data in estimating large area tree stem volume and aboveground biomass. *Remote Sensing of Environment* 82: 156-171.
- Yamaguchi, Y., Kahle, A.B., Tsu, H., Kawakami, T. & Pniel, M. 1998. Overview of Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER). *IEEE Transactions on Geoscience and Remote Sensing* 36(4): 1062-1071.