LIDAR remote sensing and imaging spectrometry for wildfire risk assessment and forest management

Contribution to YSC Davos 2008
Thematic topic: (see conference site)

Felix Morsdorf[1], Benjamin Koetz[2] and Britta Allgöwer[3]

[1]*University of Zürich , Department of Geography, e-mail: felix.morsdorf@geo.uzh.ch*
[2]*ESA-ESRIN Exploitation & Services Division, Project Section, e-mail: benjamin.koetz@esa.int*
[3]*Science City Davos e-mail: britta.allgoewer@wissensstadt.ch*

Key words: LIDAR, imaging spectrometry, wildfire management, forest inventory

INTRODUCTION

Fire risk and behavior depend heavily on the fuel properties such as the quantity of biomass, fuel moisture content, and the vertical and horizontal structure of the canopy (Allgöwer et al., 1998). Accurate information on forest fuel properties at high spatial and temporal resolutions is consequently vital for understanding the processes involved in initiation and propagation of forest fires (Keane et al., 2001; Chuvieco, 2003). Remote sensing offers the potential to provide spatially distributed information on biomass, canopy structure and fuel moisture to assess fire risk and to mitigate the impact of forest fires (Leblon, 2000). The role of remote sensing in estimating these properties has been increasing in recent years, with special emphasis on new high-resolution active and passive optical sensors. Airborne laser scanning is particularly suited to derive structural forest parameters such as tree height, fractional cover, canopy geometry and vertical distribution of aboveground biomass, as well as to derive the underlying topography. Supplementary, the water content of green vegetation can be retrieved from the detailed spectral information provided by imaging spectrometer data.

MATERIAL & METHODS

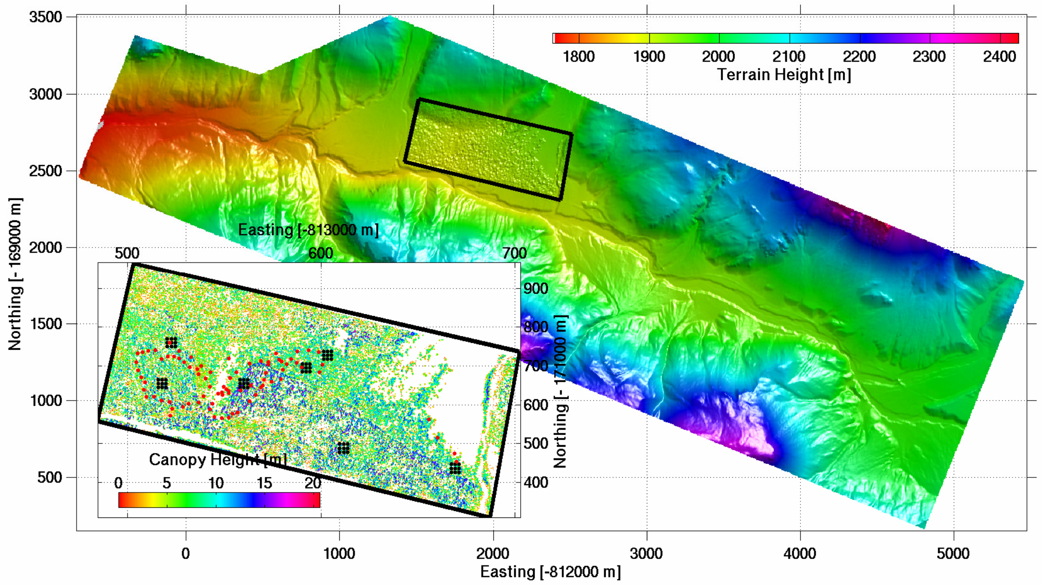

Figure 1: The Digital Terrain Model (DTM) of the Ofenpass area in the Swiss National Park. The smaller area marked by the black box was sampled with higher point density due to the lower flying height of 500 m above ground. A canopy height map of that area is displayed in the lower left. Dots mark positions of field measurements.

The study area for the acquisition of the field data is located in the Eastern Ofenpass valley, which is part of the Swiss National Park (SNP). The Ofenpass represents an inner-alpine valley on an average altitude of about 1900 m a.s.l with annual precipitation of 900-1100 mm. Embedded in this environment are boreal type forests where few, but very impacting (stand-replacing) fires were observed.

The study area has been subject to previous fuel modeling studies where three main fuel models could be identified through extensive field studies (Allgöwer et al., 1998). Based on these field measurements a map depicting the rough spatial distribution of fuel models could be described. In Summer 2002 two airborne campaigns were carried out in the SNP providing high resolution imaging spectrometer and LIDAR (LIght Detection And Ranging) remote sensing data. Exhaustive ground measurements of biochemical and biophysical parameters together with forest stand measurements of the Long-term Forest Ecosystem Research program of the WSL described the observed forest in detail. Based on the acquired data set novel methodologies were developed and validated to generate various fuel layers of the observed area (Kötz et al., 2004; Koetz et. al., 2007; Morsdorf et al., 2004; Morsdorf et al., 2006). The imaging spectrometry data provided the spatial distribution of live fuel moisture where as the LIDAR described the canopy height, fractional vegetation cover and terrain attributes such as elevation, slope and aspect in spatial resolution of up to 5 meters (Figure 1). In addition, working with the raw LIDAR returns (point cloud), a fully automated method for segmentation of single trees was implemented. The method is based on a k-means cluster analysis using local maxima from the canopy height model (CHM) as starting locations. From the segmented tree crowns, geometric information such as tree location, tree height, crown diameter and the crown base height can be derived, enabling a geometric reconstruction of the forest scene as presented in Fig. 2. About 75 percent of the dominant trees were correctly detected and the RMSE of tree height estimation was 0.6 meter (Morsdorf et al., 2004).

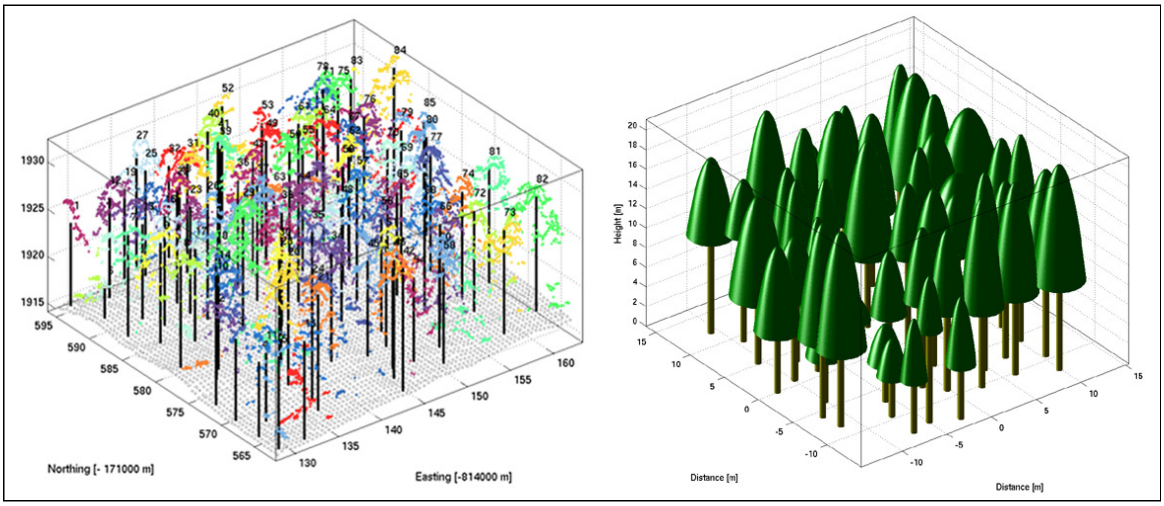

Fig. 2: Reconstruction of individual tree geometry with LIDAR data (Morsdorf et al. 2004)

RESULTS

We implemented and developed methods for the deriavtion of a number of biophysical and biochemical vegetation properties from both airborne LIDAR and imaging spectrometry data. As an examplenary application of this comprehensive dataset, we use a well known fire behavior model (FARSITE), which is able to simulate fire behavior as a function of topography, fuel bed properties, meteorologic conditions (Finney, 1998). The terrain properties (DTM, Slope and Aspect) must be on grids, whereas vegetation properties (Fuel Model, Canopy Cover, Stand Height, Crown Base Height and Crown Bulk Density) can be defined either as spatially resolved maps or as constants for the whole modeling area. We included Canopy Cover and Stand Height as spatial maps based on LIDAR data in a spatial resolution of 5 meters. For roads and riverbeds, a classification of the hyperspectral data-set was carried out, which yielded two masks providing distinct grassland and non-fuel areas. Since we wanted to study the effect of resolution on FARSITE results, we resampled each of the spatially explicit input layers into 4 different resolutions over the same spatial extent. These resolutions were 5, 10, 20 and 30 meter pixel size. Weather was set up using a typical summer day in that area, with low wind speeds, which were left constant for all model runs. For the interpretation of the sensitivity study the FARSITE outputs rate of spread (RoS) and time of arrival (ToA) based on input data in the four selected spatial resolutions have been presented in Figure 3. The observed fire behavior is dominated on all spatial scales in its general patterns by the effects of the mountainous topography. On slopes the RoS is significantly increased, effecting the speed and the direction of the fire front. The different spatial scales of the fuel bed description become apparent in the responses of the fire behavior to fuel breaks as river beds and roads. The southern extend of the fire is limited by a road (8 m wide) for the simulations of 5 to 10 meters scale whereas for the smaller scales only a larger river bed stops the fire spread. Also a small river bed is able to stop at least temporarily the fire spread in its eastern direction on the 5 meter scale. The area burnt beyond this river bed is only burnt after 16 hours contrary to the smaller scales where this area is immediately affected by the fire.

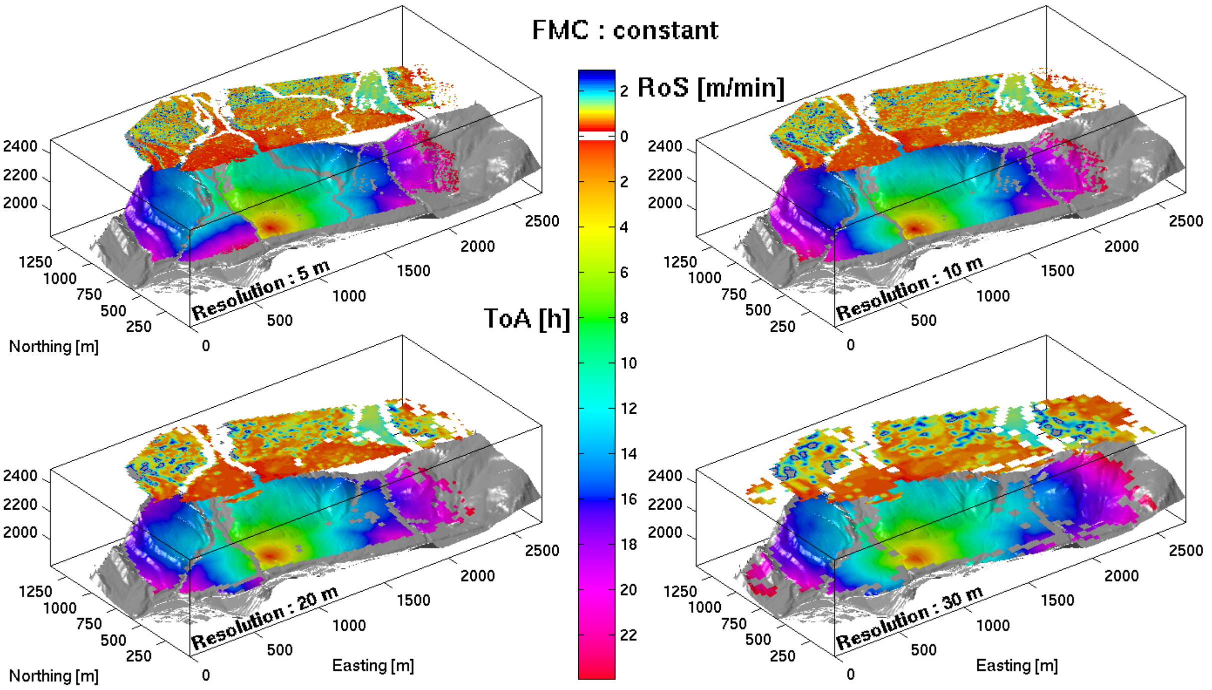

Fig. 3: Time of Arrival (ToA, bottom layer) and Rate of Spread (RoS, top layer) maps for four different resolutions, the simulation duration was 24 hours. The DTM was added in shaded gray for visibility of topographic features.

CONCLUSIONS & OUTLOOK

We used two complementary remote sensing methods, namely LIDAR and imaging spectrometry (IS) for the derivation of biophysical and biochemical vegetation properties, including location and geometry of single trees, vegetation cover and physiological information such as the fuel moisture content. These properties are relevant for a broad range of applications, from ecosystem studies to fire risk management. For the latter, we showed an example application of LIDAR and IS derived layers in a GIS based fire behavior and study the sensitivity of this model for the resolution of input layers. This is only the starting point for the application of such combined datasets, and as acquisition costs drop, other applications like flood plain monitoring will become evident. There, as well as in our application, the combination of physical information on terrain and vegetation (LIDAR) and vegetation type and status (IS) is vital for a comprehensive risk assessment. Future studies will try to exploit the potential of the combination of these data sources even further, be it by physically based models of the radiative transfer involved with LIDAR and IS or by combined classifications of fused data-sets.

REFERENCES

Allgöwer, B., Harvey, S. and Rüegsegger, M. (1998). Fuel Models for Switzerland: Description, Spatial Pattern, Index for Crowning and Torching. 3rd International Conference on Forest Fire Research / 14th Conference on Fire and Forest Meteorology, Luso, Portugal, 2605-2620.

Chuvieco, E. (Ed.) 2003. Wildland Fire Danger Estimation and Mapping. The Role of Remote Sensing Data. Singapur, World Scientific Publishing.

Finney, M. A. (1998), FARSITE: Fire Area Simulation - Model development and evaluation. USDA Forest Service, Rocky Mountain Research Station, Research Paper RMRS-4.

Keane, R. E., Burgan, R. and van Wagtendonk, J. (2001), Mapping wildland fuels for fire management across multiple scales: Integrating remote sensing, GIS, and biophysical modeling. International Journal of Wildland Fire, 10(3-4), 301-319.

Kötz, B., Schaepman, M., Morsdorf, F., Bowyer, P., Itten, K. and Allgöwer, B. (2004), Radiative transfer modeling within a heterogeneous canopy for estimation of forest fire fuel properties. Remote Sensing of Environment, 92(3), 332-344.

Koetz, B.; Sun, G.; Morsdorf, F.; Ranson, K.; Kneubuhler, M.; Itten, K. and Allgöwer, B. (2007). Fusion of imaging spectrometer and LIDAR data over combined radiative transfer models for forest canopy characterization. Remote Sensing of Environment, 106, 449-45

Leblon, B. (2000), Forest Wildfire Hazard Monitoring Using Remote Sensing: A review. Remote Sensing Reviews, 20(1), 1-44.

Morsdorf, F., Koetz, B., Meier, E., Itten, K. and Allgöwer, B. (2006), Estimation of LAI and fractional cover from small footprint laser scanning data. Remote Sensing of Environment, 104, 50-61.

Morsdorf, F., Meier, E., Kötz, B., Itten, K. I., Dobbertin, M. and Allgower, B. (2004), LIDAR-based geometric reconstruction of boreal type forest stands at single tree level for forest and wildland fire management. Remote Sensing of Environment, 92(3), 353-362.