TRACING STRUCTURAL CHANGES OF A COMPLEX FOREST BY A MULTIPLE SYSTEMS APPROACH

Thomas Schneider[1,2], Jiaojiao Tian[3], Alata Elatawneh[1], Adelheid Rappl[4] and Peter Reinartz[3]

1. Technische Universität München (TUM), Institute of Forest Management (IFM), Freising; Germany, tomi.schneider@tum.de
2. Technische Universität München (TUM), Limnological Station, Iffeldorf, Germany;
3. German Aerospace Center (DLR), Remote Sensing Technology Institute (IMF), Oberpfaffenhofen, Germany; jiaojiao.tian@dlr.de; peter.reinartz@dlr.de
4. Bavarian State Institute of Forestry (LWF), Freising, Germany; adelheid.rappl@lwf.bayern.de

ABSTRACT

An investigation on the combination of information from multiple sensors is presented, dealing with the assessment of forest structure and structural changes over time in the complex Mid-European forest of the Traunsteiner Stadtwald, a communal forest in South-East Bavaria, Germany. The starting point of the investigation was a data set from 2003 combining HyMap hyperspectral data and a 0.5m grid DSM calculated from HRSC data. A canopy height model was derived with the help of the official Bavarian State Survey DTM originating from 2001 LIDAR data. During the night of 18th to 19th of January 2007 the winter storm Kyrill caused severe damages in that forest. Using satellite data from the systems RapidEye, Cartosat-1 and ALOS Prism the changes in forest structure were analysed. Of special interest was the question whether the parameter derivation accuracy from the lower resolution satellite data are sufficient to assess the damages and to update the data bases of the Traunsteiner Stadtwald forest. The validation of the results was done on behalf of the regular forest inventory data from 1999 and 2009 respectively, supported by a LIDAR data set from 2010 for height assessment of the satellite data derived surface models.

INTRODUCTION

Remote sensing (RS) is a fast developing technique. In contrary, forestry, addressed as land use type, must continuously be managed over periods from 50 to 250 years. The main income from managed forest is from timber production. Needs are typically management driven but the importance of societal services is continuously increasing. Information input from RS should cover the needs for local operation support, at the strategical/tactical enterprise level, for policy making, in support of governmental organs, for environmental issues, etc.. Change detection studies deliver important decision support information to control forest transformation successes. By comparing the status assessed with today's sensors generation with the status assessed with the help of the sensors of the past, of course, errors will be introduced. Change detection studies should that fore be based on parameter. A forest description on base of parameter is in line with forest management data and such facilitate modelling approaches like simulations of forest growth or calamity distribution dynamics. The selection of parameters for this study was steered by a survey with forest practitioners and administrative officers [1]. The presented results are covering solely a reduced parameter set for which accuracies and changes are derived:

- Forest area (derived: gaps, border length)
- Mean stand heights
- Tree species groups coniferous / deciduous / mixed
- Tree species groups subdivided by high in three subclasses each

Despite the importance for practice we have to concede that RS still fails in assessing tree species. Accordingly health status and vitality, which are directly related to species, are unsolved challenges, while mechanical damages of the crown e.g. crown top breaks by storm or snow, are detectable at least by very high resolution (vhr) systems. On-going research is testing the success of multi-seasonal approaches which rely on the hypothesis that the phenological change profile of the species may be used for identification.

The main research questions we report are targeted to fulfil the demands of an operational forest management on the strategical/tactical level of a forest enterprise. This is the level giving an overview about the situation and assortment of the enterprise and should ideally be updated annually. The corresponding scale is the 1:10.000 mapping scale of the forest management maps of the Bavarian State Forest Administration, the parameter comparison is done on stand basis.

The investigations are subdivided in following subtasks:
- Comparison of surface model accuracies from air borne HRSC system and the space borne systems Alos PRISM and Cartosat-1
- Comparison of tree species group classification success using hyperspectral HyMap data and multiseasonal RapidEye data
- Improvement of the classification by integrating height information from the stereo data sets

The vitality/damage parameter was not investigated within this research but is implicitly included because the main damages in old grown coniferous stands are caused by the Storm Kyrill from 18th of January 2007.

METHODS

The demonstration site Traunsteiner Stadtwald (community forest of the city of Traunstein) is located in South-Eastern Bavaria, close to lake Chiemsee and the border to Austria. The investigation site is located around the central coordinates N 47°51'42''; E 12°39'20'' and covers an area of about 242ha. The soils are of typical glacier sediment origin and belong to the Swabian-Bavarian upper moraine site type (unit 14). On 18th of January 2007 storm Kyrill caused large area damages especially on pure old grown spruce stands. The Traunsteiner Stadtwald is a long term research site of the TU München forestry chairs and managed by the chair of Forest Yield Sciences. The existing data set is typical for a research collection sampled over time:

- 1998/99 and 2008/09: forest inventory and forest management planning data
- 2001 and 2010: LIDAR data of the Bavarian State Survey (point density: 2/m², 5,65/m²)
- 2003: HRSC multispectral and three line stereo data (0,5m pixel, blue, green, red, NIR)
- 2003: HyMap hyperspectral data, two stripes (5m pixel, 125 bands VIS, NIR, SWIR)
- 2008: Alos PRISM three line stereo data (2,5m pixel, panchromatic)
- 2008: Cartosat two line stereo data (2,5m pixel, panchromatic)
- 2009 and 2011: RapidEye multispectral data (6,5m pixel, blue, green, red, red edge, NIR)
- 2009: digital photographs of the regular Bavarian State Survey coverage

For operational usage the data set is much too expensive. For research the data set allows answering the formulated research questions related to monitoring and change detection issues.

Preprocessing: All data sets were co-registered to the geographic reference system which is Germany Gauss-Krueger zone 4 for the Traunsteiner Stadtwald study site. Because of the mono-temporal parameter determination the standard radiometric corrections as delivered by the DLR HyMap processing chain and the RapidEye Company processing chain were used without further adjustments. The same applies for the panchromatic stereo data from Alos PRISM and Catosat-1 and the High Resolution Stereo Camera (HRSC) data provided by DLR Berlin Adlerhorst.

Forest area determination: The forest area was determined from HyMap data for 2003 and from RapidEye data for 2009. The layer "land use" (TN, tatsächliche Nutzung) of the Official Topographic-Cartographic Information System (ATKIS-Basis-DLM Amtlich Topographisch-Kartographisches Informationssystem) of the Bavarian State Survey was used for accuracy assessment. The definition of this layer fits best the "forest" objects derivable from RS data [2].

Stand heights determination: LIDAR system derived height information is presently the reference in tree height and crown size determination. The 1m, 2m and 5m grid digital terrain model (DTM) for Bavaria is based on LIDAR data. The DTM service of the Bavarian State Survey creates the opportunity to combine digital surface models (DSM) extracted from different systems and to derive canopy height models (CHM) or normalized DSM (nDSM) by difference. Dependent on the resolution of the original data set single trees and crown size or stand level heights may be obtained. Within this study the method was used to:

- Calculate canopy heights from the airborne HRSC data set and the spaceborne Alos PRISM and Cartosat-1 data sets
- To derive the forest heights change between the 2001/2003 and the 2008/2010 observation periods (including the Kyrill event)
- To evaluate the improvement in forest classification by introducing stand heights (object heights) as additional parameter

DSMs with 5 meter resolution have been generated from Alos PRISM and Cartosat-1 stereo imagery using the Semi Global Matching (SGM) algorithm implemented at DLR [3]. DSM quality assessment was performed on base of LIDAR data from year 2010.

Forest type classification: Tree species group classifications are performed with object-based analysis using eCognition 8 of the Trimble Company. The analysis was restricted on the forest class (forest mask) delineated in the first processing step (level 1). The classification method was adapted to both data set of HyMap (2003) and RapidEye (2009). The class hierarchy starts with forest/non forest, coniferous/deciduous.For separating coniferous and deciduous in the HyMap data the minimum noise fraction index (MNF with MNFB = minimum noise fraction band) was used:

$$MNF\ Index = \frac{(MNFB\ 10 + \ MNFB\ 7 + MNFB\ 4 + 300)}{(MNFB\ 9 + MNFB\ 6 + MNFB\ 3 + MNFB\ 1 + 400)}$$

While for classifying coniferous and deciduous with RapidEye data a ratio index was calculated according to following equation:

$$Ratio\ Index = \frac{Green * RedEdge}{Red}$$

Mixed forest was determined by using the share of coniferous and deciduous per stand at a 20% threshold. Finally each base class was subdivided on behalf oft tree height classes using the nDSM information and the thresholds >22m, <22m and >12m and <12m arriving at eleven end-classes.

RESULTS

DSM quality evaluation: Figure 1a-d shows the Traunsteiner area in an aerial photograph with the height profiles for residential, forest, meadow surface types and the DSMs from LIDAR_2001, HRSC_2003 and LIDAR_2010. For evaluating the quality of DSMs from the airborne and spaceborne stereo imagery, a pixel wise quality assessment has been done for forest, residential and in the meadow-ground area. HRSC DSM from year 2003 and the spaceborne DSMs from Alos PRISM and Cartosat-2 are compared with two quality levels of LIDAR_2001 and 2010 DSMs.

As shown in Figure 2, buildings in residential area can be well separated from all three airborne DSMs, although building edges from Airborne-DSM is relatively less sharp than LIDAR-DSMs. In the forest area, LIDAR DSM is able to separate single trees in some area, even with the lower quality DSM from year 2001. HRSC DSM performed slightly worse. However the main tree height from HRSC DSM is well matched with two LIDAR DSMs. In the ground area, all of the LIDAR DSMs and the HRSC DSM display smooth surface of the terrain. In case of DSMs from satellite stereo images the relatively worse quality is obvious (Figure 2). Therefore, these DSMs are not good enough for residential area monitoring, since they cannot separate single houses. However, both of the DSMs from Cartosat-1 and Alos PRISM show better performance in forest area. Although they are not able to separate single trees in some area, the main trend of forest distribution can be well shown on them. Moreover the tree heights are well matched between these

DSMs. In the ground area uniform "noise" values, with about 2~5 meters, are well presented, which could be expected as it is within the range of the pixel size of Alos PRISM and Cartosat-1 data, and cannot introduce large false alarms in forest change detection. Therefore, the DSMs from satellite stereo data is theoretically suitable for forest change detection.

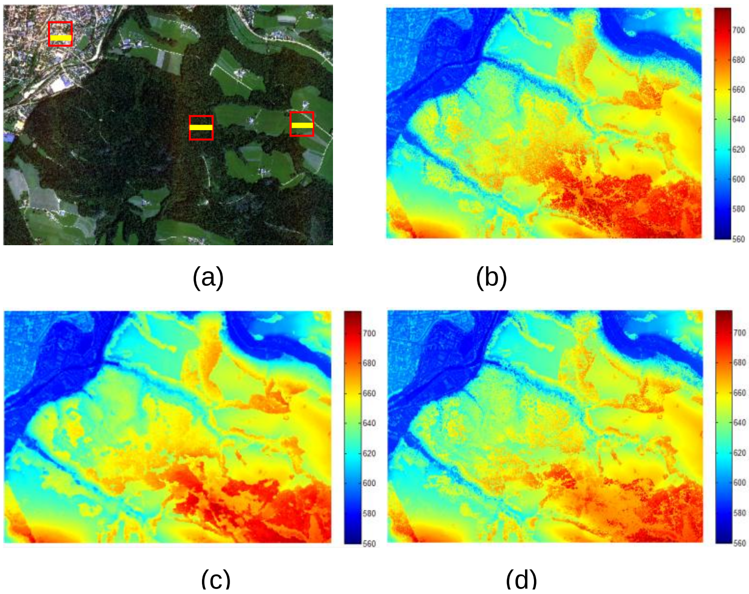

Figure 1: (a) Airborne data in Traunsteiner Stadtwald area with the height profiles lines for residential, forest, meadow; (b) LIDAR-2001_DSM; (c) HRSC_2003-DSM; (d) LIDAR_2010_DSM)

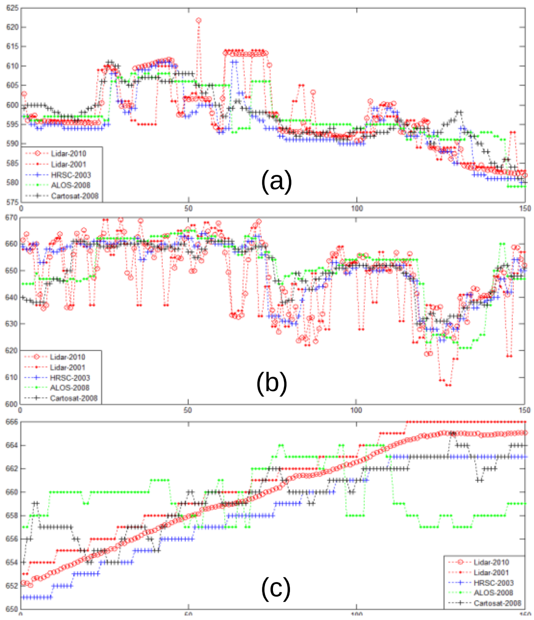

Figure 2: Profile comparison along the yellow line (

Change Detection with DSMs: From the DSM_pre and DSM_after Kyrill, the difference DSMs were obtained and the damage forest area thus detected.

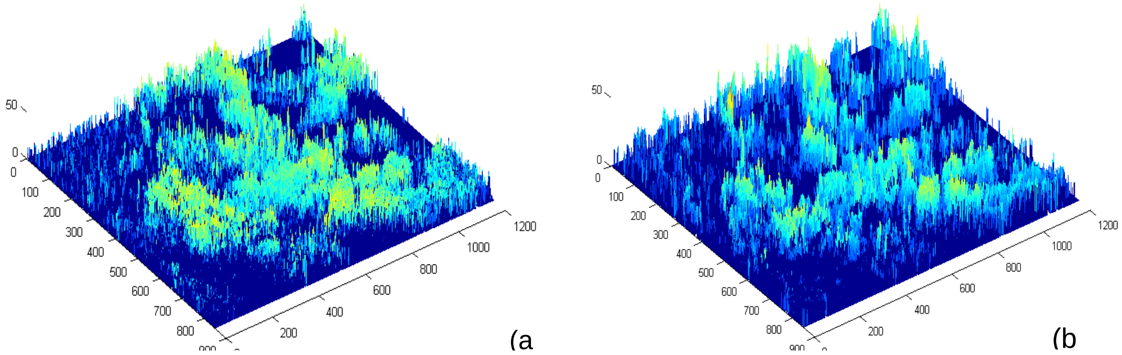

Figure 3: Height difference maps (a) LIDAR_2010-LIDAR_2001; (b) ALOS_2008-HRSC_2003;

Error! Reference source not found. shows the height change map between LIDAR_2010 and LIDAR_2001 (**Error! Reference source not found.** a) espectively ALOS_2008 and HRSC_2003 (**Error! Reference source not found.** b). The results are quite similar; the areas damaged by storm Kyrill are at least well detected with both system pairs.

DSM change detection result evaluation: In order to allow a quantitative evaluation of the effectiveness of the DSM from stereo images, and also to study the influence of the DSM quality on the change extraction procedure, we compare the extracted change map with a referenced change mask produced from the two relatively higher qualities LIDAR DSMs. The morphological filters were used to smooth the mask.

Table 1: Change detection evaluation results

Data pairs	False alarm	Missed Alarm	Overall Error	Kappa Accuracy
LIDAR_2010-LIDAR_2001	0.7071	0.2573	0.0509	0.5801
ALOS_2008-HRSC_2003	0.4385	0.5577	0.0526	0.4428
Cartosat_2008-HRSC_2003	0.4127	0.4793	0.0771	0.5138
ALOS_2008-LIDAR_2001	0.6750	0.3850	0.0560	0.5079
Cartosat_2008-LIDAR_2001	0.6207	0.3095	0.0491	0.5719

The change detection accuracy evaluation method shown in [4] is adopted in this research.

Table 1 summarizes the error matrix of the change detection results from the 5 tests. The Kappa accuracy from stereo imagery generated DSMs are a little lower, but does not have distinguish difference with the result from LIDAR DSMs. The overall errors are under the similar situation. It has to be noted that from visual comparison, almost all of the change locations in the reference map are included in the detected change mask.

Forest area determination: The ***forest area*** was determined from HyMap data for 2003 and from RapidEye data for 2009. Compared to the ATKIS layer TN an agreement of 97% for the 2003 data set and of 98% for the 2009 data set was obtained.

Forest type classification: The forest type classification into coniferous, deciduous and mixed stands was done on three levels of detail on base of HyMp data for 2003 and Rapid Eye data for 2009 as described in the method section above (Figure 4 a,c).

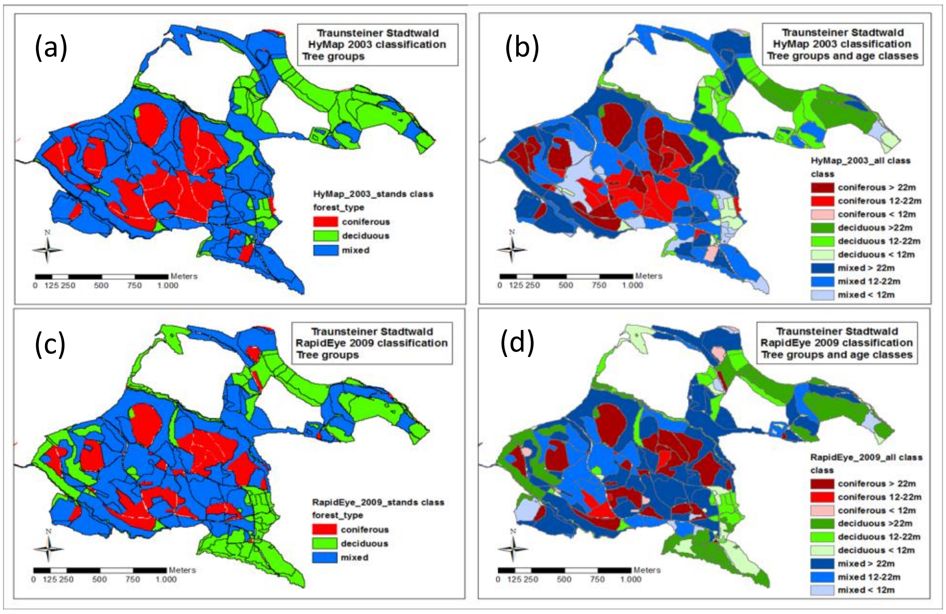

Figure 4: Forest type classification on tree group and age class subdivided tree group level for the HyMap data set from 2003 (first row) and the RapidEye data set from 2009 (below)

The Mixed class was calculated by summing up the shares of coniferous and deciduous objects within a stand as defined by forest management planning. By using the height information from the HRSC nDSM_2003 and the Alos PRISM nDSM_2008 the above forest stand groups were subdivided into three subclasses each. Such the final classification results for 2003 and 2009 shows nine classes each (Figure 4 b,d). Using allometric functions developed on permanent sample plots in Bavaria, height classes are easily to be transformed in to age classes, which are required for forest management planning.

***Change detection quantification**:* On base of the classification results the changes occurring between 2003 and 2009 were calculated for each of the nine classes. Figure 4 shows the changes displayed as bar graph. According to the promoted goal of forest transformation toward a species rich, highly structured forest the especially the coniferous class of mean forest age is covering 2009 a much smaller area than 2003.

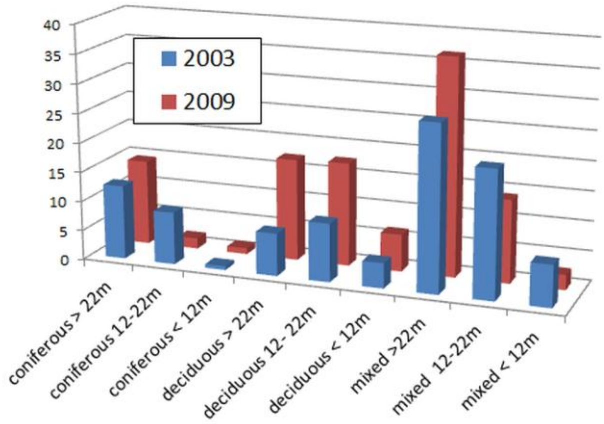

Figure 5: Changes of the area covered by the nine forest type classes between 2003 and 2009

While parts of the stands classified 2003 into the mean category passed over in 2009 to the "high" class of old tree stands, the Kyrill event marked by a reduced area of pure coniferous forests. Interesting fact is, that the "old grown" classes with an estimated age of more than 50 years, cover larger areas in 2009. This may be interpreted as a management strategy trying to protect the old and valuable timber assortments until the market prices are appropriated. The area covered by deciduous classes significantly increased.

CONCLUSIONS

For tree species differentiation, meaning the economic most important coniferous tree species spruce, pine, fir and Douglas fir and the deciduous tree species oak, beech, maple, ash, etc. a hyperspectral resolution did not brought advantages compared to multispectral imaging in the VIS and NIR. The stereo registration capability allowed the derivation of stand height classes and such the access toward an age estimation by the help of allometric functions calculated from long term growth observation plots. The accuracy of stand height estimates was better from airborne vhr systems like the HRSC or LIDAR. For forest applications the satellite based systems Alos PRISM and Cartosat-1 with 2,5m ground resolution proved to be sufficient, at least for the strategical/tactical level of a forest enterprise.

A cost/benefit optimized sensor system for forest monitoring (and change detection) may be configured with 5 to 8 spectral bands in the VIS, RedEdge and NIR combined with a three line stereo imaging system for height estimations. Additionally the RapidEye constellation with five identical satellites is suggested because of his fast reaction capability in the disaster case.

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