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Article

Pan-Arctic Land Cover Mapping and Fire Assessment for the ESA Data User Element Permafrost

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Keywords: Land cover harmonization, pan boreal, vegetation continuous field, burned area, GlobCarbon, MODIS.

Summary: The paper presents first results of a pan-boreal scale land cover harmonization and classification. A methodology is presented that combines global and regional vegetation datasets to extract percentage cover information for different vegetation physiognomy and barren for the pan-arctic region within the ESA Data User Element Permafrost. Based on the legend description of each land cover product the datasets are harmonized into four LCCS (Land Cover Classification System) classifiers which are linked to the MODIS Vegetation Continuous Field (VCF) product. Harmonized land cover and Vegetation Continuous Fields products are combined to derive a best estimate of percentage cover information for trees, shrubs, herbaceous and barren areas for Russia. Future work will concentrate on the expansion of the developed methodology to the pan-arctic scale.

Since the vegetation builds an isolation layer, which protects the permafrost from heat and cold temperatures, a degradation of this layer due to fire strongly influences the frozen conditions in the soil. Fire is an important disturbance factor which affects vast processes and dynamics in ecosystems (e. g. biomass, biodiversity, hydrology, etc.). Especially in North Eurasia the fire occupancy has dramatically increased in the last 50 years and has doubled in the 1990s with respect to the last five decades. A comparison of global and regional fire products has shown discrepancies between the amounts of burn scars detected by different algorithms and satellite data.

Zusammenfassung: *Pan-arktische Landbedekkungskartierung und Feuerbeurteilung für das ESA Daten Nutzerelement Permafrost.* In diesem Paper werden die Ergebnisse einer land cover Harmonisierung und Klassifikation verschiedener Vegetationsprodukte auf pan-borealer Ebene dargestellt. In der vorgestellten Methodik werden globale und regionale Produkte kombiniert und Bedeckungsinformationen verschiedener Vegetationstypen und brachliegenden Flächen auf pan-arktischer Ebene als Teil des ESA Data User Element Permafrost abgeleitet. Anhand von produktspezifischen Legendenbeschreibungen werden die Landbedeckungsklassen zu vier LCCS Klassifikatoren zusammengefasst, die mit dem MODIS VCF Produkt kombiniert werden. Ziel dieser Kombination von land cover und VCF, ist die Ableitung einer so genannten „best map", die Bedeckungsinformationen über Bäume, Sträucher, Gräser und brachliegende Flächen in Russland beinhaltet. Für zukünftige Arbeiten ist die Ausweitung der Methodik auf den panborealen Bereich vorgesehen.

Die Vegetation stellt eine Isolationsschicht dar, die den Permafrostboden vor Wärme- und Kälteeinflüssen nachhaltig schützt. Eine Degradation der Vegetationsdecke, durch beispielsweise Feuerereignisse, hat großen Einfluss auf die Temperaturdynamiken des Permafrostes. Feuer spielen einen entscheidenden Faktor in der Veränderung von Ökosystemprozessen (z. B. Biomasse, Biodiversität, Hydrologie, usw.). In Nordeurasien ist ein dramatischer Anstieg von Feuerereignissen in den letzten 5 Dekaden zu verzeichnen, der sich in den 90er Jahre bezüglich der letzten 50 Jahre verdoppelte. Ein Vergleich von globalen und regionalen Feuerprodukten, abgeleitet aus Fernerkundungsdaten, zeigten Diskrepanzen in der Detektion von Brandnarben durch verschiedene Produkte.

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1 Introduction

In permafrost regions the vegetation and also the land surface texture is strongly affected by the uppermost soil layer (active layer) which is influenced by seasonal freeze/thaw dynamics (Fig. 1). This layer varies in depth from several centimeters in high northern latitudes to a few meters in the sporadic permafrost zones. All permafrost zones have a defined characterization of the existing landform respectively their vegetation structure. The land cover varies from lower vegetation species to shrublands and large boreal forest areas due to the dynamic of the active layer (Anisimov & Reneva, 2006). Primary tundra areas are the typical landform in permafrost regions. Due to global warming aspects shifting of vegetation zones will impact the organic vegetation layer.

The usage of Earth observation instruments is showing that changes in the pan-boreal tundra ecosystems are forced by increasing temperatures and this also alters the land cover and vegetation structure in different forms (Fig. 1). The vegetation and distribution of water bodies are primary important because of their spatio-temporal dynamics. Furthermore by continuous and consistent monitoring of the physical surface (land cover) in permafrost regions, an integrated observation and assessment system could be generated.

Fire is an important disturbance factor which affects all processes and dynamics in ecosystems. The influence of fires on the land surface parameters like biomass, biodiversity and hydrological processes has been analyzed over the last decades (Langmann et al. 2009, Csiszar et al. 2004, Loboda & Csiszar 2004). Especially in northern Eurasia the fire occupancy has dramatically increased in the last 50 years and has doubled in the 1990s with respect to the last five decades. The global climate change, which is strongly prevalent in these regions, is one of the major factors which affects the duration, frequency and the intensity of fires (ACIA 2004). The conversion of organic matter into carbon dioxide and the release of greenhouse gases to the atmosphere are resulting in a feedback reaction of the global climate and the fire occurrence frequency (Schuur et al. 2008, Cuevas-Gonzales et al. 2009). Due to the large regions the fire protection is very limited which results in inconsistencies in fire statistics of Russia (Soja et al. 2004, Conard & Invanova 1997). Apps et al. (1993) highlighted that the analysis of fires in Russia need to have high priority since the boreal region is one of the largest carbon sinks.

Fire products from MODIS and GlobCarbon which are based on remote sensing data shows high potential to detect fire affected areas over large regions. International programs like IGBP, GOFC-GOLD and GTOS use remote sensing capabilities for the monitoring of fires and their impacts to global climate change. In this paper a comparison of two global and two regional burned area products is done to analyze similarities and differences between different types of data.

The proposed concepts in this work are linked towards a monitoring system (Permafrost Information System) as part of the ESA "Data User Element Permafrost" (DUE Per-

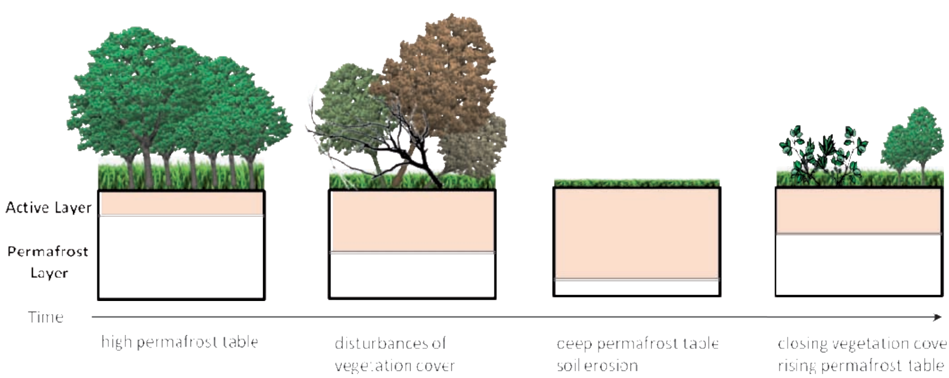

Fig. 1: Permafrost-Vegetation Interactions in time redrawn after (Benninghoff 1952).

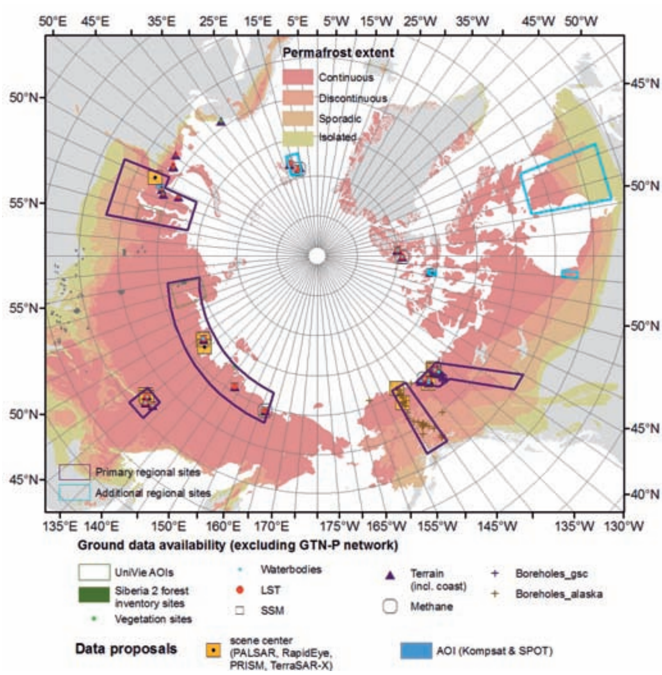

Fig. 2: Circum Arctic-Layer Permafrost System (CAPS) Version 1.0 (note: not a product from the DUE PF) northern hemisphere with indicated preliminary service case regions of the DUE Permafrost (local and regional test sites for lake change and vegetation mapping) (Source: Observation Strategy Paper).

mafrost) on the basis of 5–7 high resolution local sites, regional study sites and a pan-boreal scale monitoring level (Fig. 2).

The local monitoring sites are situated in specific regions of the pan-arctic zone with multitemporal very high resolution data coverage using Key-Hole data sets from Corona and Hexagon missions (1960–70s), RapidEye data, Kompsat-2 data, Landsat MSS and Landsat ETM+ data. The pan-boreal land cover product is based on the harmonization of available global and regional vegetation products. The final purpose of the local scale water body/change and vegetation mapping concept for the DUE Permafrost is (1) to provide a snapshot based overall lake change information with a resolution that detects fine scale thermokarst lake change, (2) to provide detailed information for upscaling analysis for regional and pan-arctic land cover levels and (3) to compliment process understanding and permafrost degradation modeling with information derived on sites with ground measurements and process understanding.

To create a comprehensive modeling framework for the permafrost state a list of other Earth observation (EO) based land surface products has been proposed (ESA User Requirement Document – URD). Water bodies and land cover have been defined as one of the key EO-based requirements. Other important parameters for permafrost monitoring are land surface temperature, soil moisture, snow cover extend, snow water equivalent, terrain elevation, elevation change/subsidence and methane emissions. The challenge of creating these products can be explained with the temporal and spatial resolution requirements of these products and the needed spatial coverage (e. g. for methane).

2 Pan-Boreal Land Cover Analysis

The analysis of vegetation structures and dynamics on pan-boreal scale in the Data User Element Permafrost will be carried out by using global and regional vegetation as well as fire products (e. g. GlobCarbon). Based on the user requirements of the DUE Permafrost it is the aim to use existing products to identify and regionalize patterns and processes through integrating and synthesizing Earth observation information from multiple information sources. The main goal will be to (1) detect large cumulative land change, spatial indicators and hot spot areas, (2) analyze inter-annual, intra-annual dynamics and long-term trends and (3) support to analysis on local scale as well as field surveys and the investigation of the relationships on different observation variables. The integration of global and regional vegetations and fire products into the observation strategy for land cover on pan-boreal scale depends strongly on the requirements defined by the user group in the DUE Permafrost. These needs which were defined by the user group for the pan-boreal scale are area percentage of vegetation physiognomy, barren and disturbance regimes (e. g., fire).

2.1 *Data and Products*

The land cover and fire products which are used in the DUE Permafrost are based on different product algorithm, input satellite data, legends as well as spatial and temporal resolution. One of the key issues will be the harmonization of global and regional products to meet the requirements of the user group.

For the parameter land cover global products like GlobCover, MODIS Land Cover and Vegetation Continuous Fields (VCF), SYNMAP and additional regional products are analysed. GlobCover is derived from MERIS (Medium Resolution Imaging Spectrometer) multi-temporal satellite data of the years 2005 and 2006. This product, with a spatial resolution of 300 m, represents the Earth surface by 22 land cover classes based on the Land Cover Classification System (LCCS) by Di Gregorio & Jansen (2005) (Arino et. al 2007a). The product generation is performed by supervised and unsupervised classification approaches for each of the so called equal-reasoning areas. The yearly MODIS land cover product (17 classes – IGBP) with a spatial resolution of 500 m uses the MLCCA (MODIS Land Cover Classification Algorithm) to extract land cover information from multitemporal MODIS (Moderate Resolution Imaging Spectroradiometer) satellite data on board of Terra and Aqua. The MLCCA uses a superviesed classification approach by extracting land cover information from a training database. Additional information like BRDF, texture, land surface temperature, etc. are integrated into the algorithm (Friedl et al. 2002, 2010). The SYNMAP product (48 classes) is a best estimate classification which was developed by the synergetic combination of the land cover products GLCC (Global Land Cover Characterization), GLC2000 (Global Land Cover 2000) and MODIS. In the algorithm the land cover information from each dataset is used to convey an affinity score, which describes the similarities and discrepancies between the products (Jung et al. 2006). MODIS VCF provides information about the cover percentage of trees, herbaceous and barren within a 500 m pixel. The principles of the algorithm is based on DeFries et al. (2000) but was improved in recent years. A regression tree uses MODIS reflectance as well as training data and NDVI values to extract the cover percentage for each pixel (Hansen et al. 2002).

Different global and regional fire products will be used in the DUE Permafrost. The MODIS (500 m) and GlobCarbon (1 km) products are showing regions of burn scars over the pan-arctic area since 1998. The World Fire Atlas (WFA) makes it possible to identify fire hotspots since 1995. Two regional products based on satellite data from NOAA/AVHRR and SPOT representing burned areas since 1996 (AVHRR) and 2000 (SPOT) (Bartalev et al. 2007, Sukhinin et al. 2004). The MODIS product identifies burned area by using information of the reflectance changes in different spectral channels (Roy et al. 2002, Roy et al. 2005). GlobCarbon is using different algorithms to extract burned areas out of ATSR-2, AATSR and SPOT-Vegetation satellite data (Roy & Boschetti 2008, Simon et al. 2004). The active fire product (WFA) is derived to identify fire hotspots by using satellite data from ATSR-2, AATSR (Arino et al. 2007b).

2.2 *Land Cover Harmonization Methodology*

The user requirements have shown the need of information about percentage area of vegetation physiognomy and barren on pan-arctic scale. The aim will be to extract this information from different land cover products by harmonizing existing land cover products to a synergetic product. In the context of land cover characterization a harmonization can be understood as a process whereby the similarities between existing datasets are emphasized and inconsistencies are reduced (Herold et al. 2006).

A first step of the processing chain will be the aggregation of land cover products to predefined LCCS classifier (trees, shrubs, herbaceous, barren – Fig. 3). In this context an extraction of minimal and maximal percentage cover information for each classifier from the legend description of the land cover products is done. The range between the minimal and maximal cover information will be used as weighting factor in the harmonization process. In example, MODIS (IGBP) defines a tree cover threshold from 60 % to 100 %. This results in a factor of the thematic precision (Tpre) of 0.6, which is higher than the definition for forest classes in LCCS with a tree canopy > 15 % (Tpre = 0.15). The narrower the class description, the higher will be the weight of that land cover class during the product combination. The calculation will be done for each classifier (trees, shrubs, herbaceous, barren). After the conversion of land cover products to percentage cover information the datasets will be linked to the MODIS VCF products. The information of the minimal, maximal and the mean percentage cover will be correlated to the VCF product which belongs to each classifer. The pair which is showing the highest correlation is used for the combination of land cover and VCF datasets. Since MODIS VCF only provides information for trees, herbaceous and barren cover our aim is to extract information of shrub cover by using the percentage relationship between the classifier shrubs and herbaceous harmonized from the land cover products. The final synergy product consists of four components where each of them describes the percentage cover of the classifier.

The fire products are integrated by the identification of fire affected hot spot areas based on the information of burn scars and active fires. Due to different temporal and spatial resolutions it is useful to combine these products to build a fire affected area database for the pan-arctic scale (Fig. 4). Therefore it is

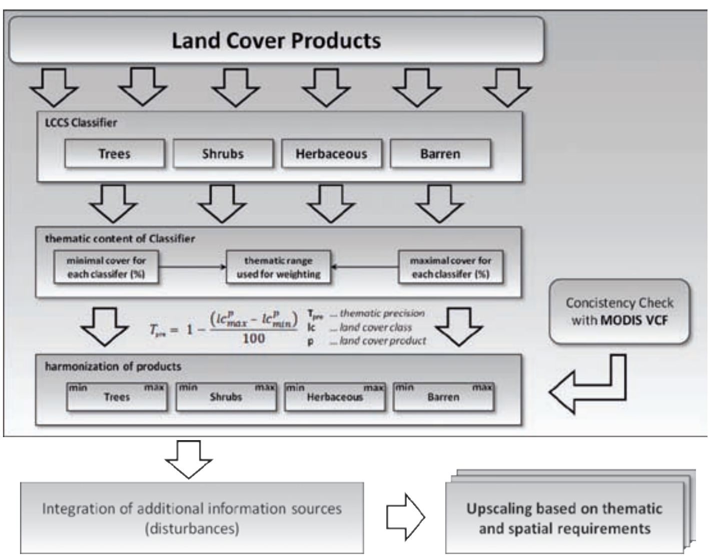

Fig. 3: Harmonization approach of different global and regional vegetation products.

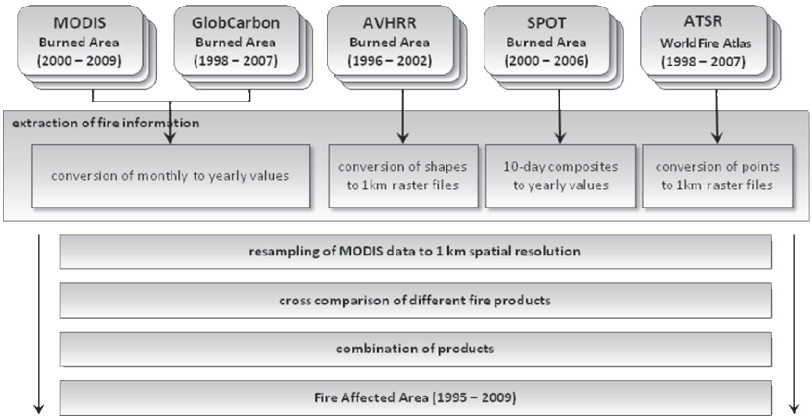

Fig. 4: Building a fire affected area database on pan-arctic scale using global and regional fire products.

mandatory to take similarities and disagreements of the products into account which can be extracted by cross comparison of the products. For each fire affected area a quality flag dataset will generated which is based on the agreement between the products.

2.3 *Results*

Harmonization of vegetation products to LCCS classifier

The results of the harmonization of the land cover products to LCCS classifier were corre-

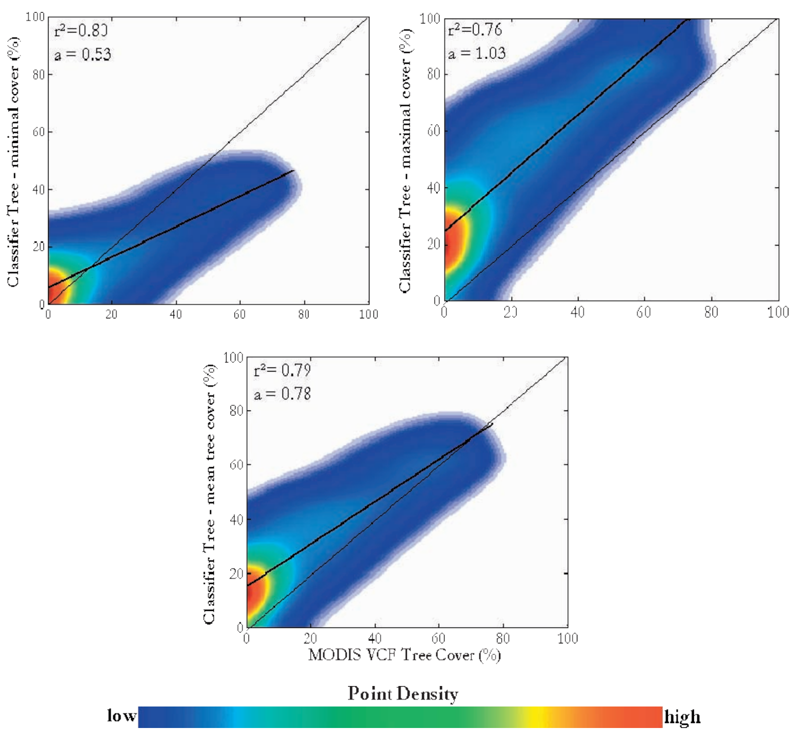

Fig. 5: Comparison of tree cover percentage extracted from land cover products with MODIS VCF tree cover.

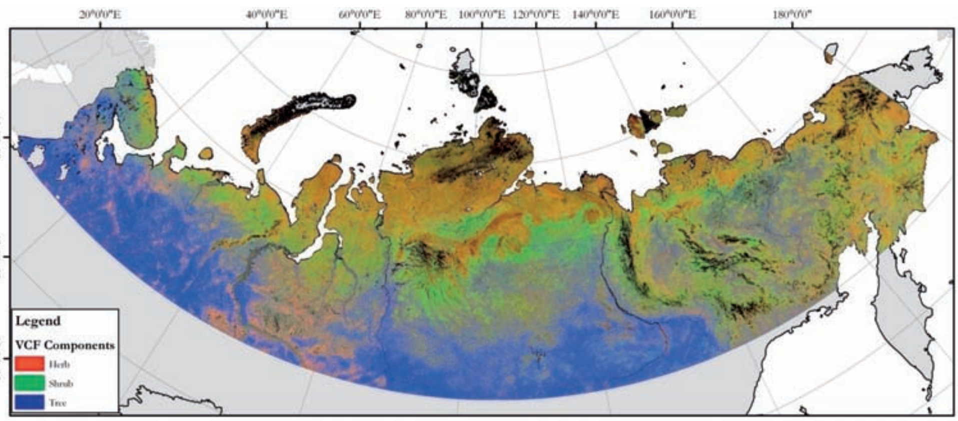

Fig. 6: Final synergy product showing the percentage cover of trees (blue), shrubs (green), herbaceous (red) and barren (black).

lated to MODIS Vegetation Continuous Fields datasets. In Fig. 5 a comparison of the minimum, maximum and mean percentage cover of the classifier tree and the VCF tree component for Russia above 60 degree north is shown in a point density cloud. The minimal (upper left) and maximal (upper right) classifier seems to be under- and overestimating the VCF tree cover values, respectively. The mean tree cover values (lower middle) from the land cover classifier are showing the best correlation with the VCF product for all three components. Based on the described methodology the mean component of the classifier and the VCF product for trees will be used for the synergy product by calculating the mean between these datasets. The same approach was used for the classifier herbaceous and barren. Both, herbaceous and barren classifiers are showing lower correlation with the VCF components.

To extract the percentage cover of shrublands the information from the classifier shrub was correlated to all VCF components to identify where the information of shrub cover is comprised. The highest dependency was detected with the VCF herbaceous dataset. Since MODIS VCF only provides information about trees, herbaceous and barren areas, the goal is it in terms of insulation of the permafrost soil to extract information of shrublands by the harmonization. By using the percentage relationship between the classifier shrub and herbaceous a dataset which provide percentage cover information for shrublands was calculated. The final synergy product consists of the four LCCS classifiers which are representing the percentage cover information for trees (blue), shrubs (green), herbaceous (red) and barren (black) in each pixel (Fig. 6). Each Pixel equals to 100 % by summarizing all components. This product will be used as boundary condition for the modeling of permafrost distributions by the integration of different parameters like land surface temperature, soil moisture and disturbances (e. g., fire).

Comparison of global and regional fire products in Russia

In this study four burned area products for Russia were compared. Two global (MODIS and GlobCarbon), two regional burned area datasets (AVHRR and SPOT) and the active fire product (World Fire Atlas) were used to create a fire affected area database for the years 1995 to 2009. This database is a combination of all available datasets and provides information about (1) the amount of fire affected areas which can be identified in all products in Russia during the last 14 years, (2) the agreement between the products which can be used as quality information for the detected burn scar and (3) it permits the identification of hot spot areas where a high frequency of fires can be observed.

Fig. 7 is showing the variability of burned areas and active fire as well as the agreement

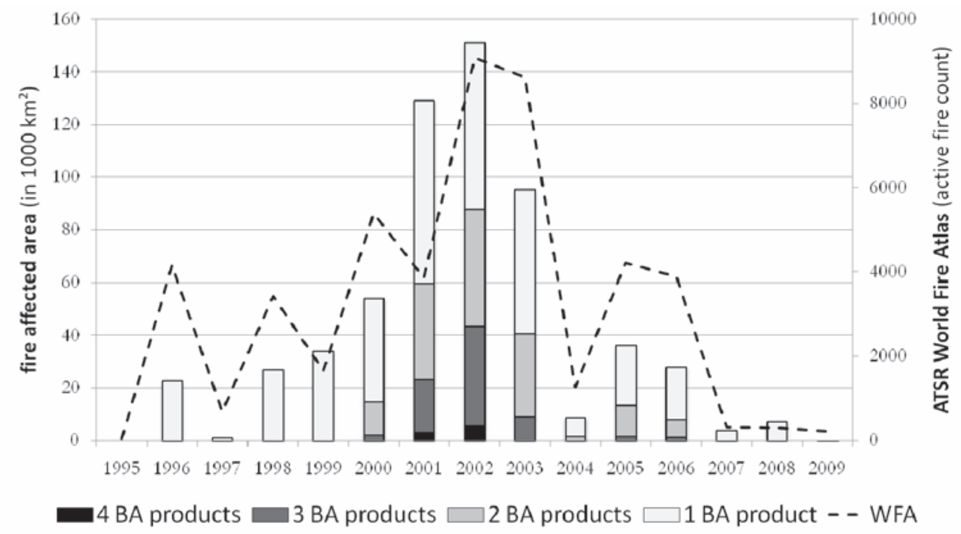

Fig. 7: The agreement of four burned area products for the area of Russia for the years 1995–2009.

between the global and regional burned area products during the last 14 years. It is distinct, that the period from 2001 to 2003 shows the highest fire activity. In contrast, the years at the end of the 1990s and from 2004 up to now showing a fairly lower fire occurrence.

The agreement between the burned area products can be defined as fairly poor during the whole time period. It is to mention that not all four products are available for whole time span. As a reason for the product availability an agreement between all products is only available for the years 2000 to 2002 and an agreement of three products for seven years (2000 to 2006). Fig. 7 shows that the highest amount of burn scars, which can be observed in the fire affected area database, are the result of the detection of only one product algorithm. Especially the years 2001 to 2003, which shows the largest abundance of burned areas seem to be dominated by the detection of only one product. Furthermore a trend can be identified which can be described as: the higher an agreement between burned area products, the lower will be area of the burn scar in the fire affected area database.

The poor agreement between the different fire products can have many reasons. (1) The raw data, which is used for the identification of burn scars, can be contaminated by clouds, smoke or aerosols which are prevalently existent in fire regions. (2) The data availability of useful images can be limited due to weather condition and satellite tracks especially in the high northern latitudes. (3) The majority of burn scar detection algorithms utilize fixed thresholds for different spectral channels for the extraction in multispectral images. The use of robust classification features, like image specific adjusted thresholds, can avoid misclassification of fire scars. (4) Furthermore, the coarse spatial resolution of 1 km can be a reason for a poor agreement between the fire products. Mixed pixels which include both non-burned and burned areas can be detected in a different way by different algorithms, which lead to a poor agreement between the products.

3 Conclusions

The proposed methodology shows the ability of global and regional vegetation datasets to extract cover percentage information for different vegetation physiognomy and barren areas. Based on the legend descriptions of each global and regional land cover product it was possible to harmonize the datasets to four predefined LCCS classifiers which were linked to the MODIS Vegetation Continuous Field product. Through synergetic combination of the harmonized land cover information and VCF products it was feasible to derive a best estimate dataset which provides information about percentage cover for trees, shrubs, herbaceous and barren areas.

A validation for all utilized products is not available. This leads to a propagation of errors from each dataset to the synergy product. Nevertheless, an advantage of a harmonization and combination is to reduce uncertainties and inconsistencies of different products. The extraction of percentage cover information seems to be a useful harmonization approach. However a definition of percentage cover values for different land cover units depends strongly on the products legend description. The Land Cover Classification System (LCCS) has a high potential as it is working with different hierarchy level. This enables to adjust the described methodology in that way, that each class can contain different vegetation information which can be differentiate. With the conversion of land cover classes to percentage cover information for vegetation physiognomy and barren the possibility and quality of scaling could be improved. As this product will be used for modeling approaches on pan-arctic scale which requires a very coarse resolution of approximate 25 km the information of higher resolution products (1 km) are integrated. Future work will concentrate on the expansion to the pan-arctic scale as only the area of Russia was tested with this methodology.

The comparison of different burned area products in the permafrost regions of Russia has shown low agreements. These products are based on different satellite data and algorithms. A combination of all datasets and the World Fire Atlas was used to create a fire affected area database. In this database the amount of fire affected regions was comprised. The agreement between these products is used to provide confidence information. The more products showed an agreement, the more confident is the burn scar detection.

Future work will be the expansion of the introduced methodologies to the pan-boreal scale as well as the integration to the Permafrost Information System and modeling approaches in the DUE Permafrost. One key issue will be the update of the Circum Arctic Vegetation Map by Walker et al. (2005) with the derived land cover information.

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