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Improving arable land heterogeneity information in available land cover products for land surface modelling using MERIS NDVI data

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Abstract

Regionalization of physical land surface models requires the supply of detailed land cover information. Numerous global and regional land cover maps already exist, but generally they do not resolve arable land into different crop types. However, the characteristic phenological behaviour of different crops affects the mass and energy fluxes on the land surface and thus its hydrology. The objective of this study is the generation of a land cover map for Central Europe based on CORINE Land Cover 2000, merged with CORINE Switzerland, but distinguishing different crop types. Accordingly, an approach was developed, subdividing the land cover class arable land into the regionally most relevant subclasses for Central Europe using statistical data from EUROSTAT. This database was analysed concerning the acreage of different crop types, taking a multiseasonal series of MERIS Normalized Difference Vegetation Index (NDVI) into account. The satellite data were used for the separation of spring and summer crops. The hydrological impact of the improved land cover map was modelled exemplarily for the Upper Danube catchment.

1 Introduction

The land surface and its properties are highly influenced by human activities such as agriculture or surface sealing. Land use/cover information is a key component of climate and hydrological models since the land cover primarily controls the energy fluxes at the land surface (Monteith and Unsworth, 1990; Lu and Shuttleworth, 2002; Masson et al., 2002). In a land use/cover map, each pixel of the land surface is associated to a label that characterizes the land use/cover following a predefined nomenclature. The accuracy of the land use/cover products has a strong effect on the model results (Ge et al., 2007). The regional hydrological relevance of the mapped agricultural land cover heterogeneity is the focus of this paper.

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1.1 Existing land use/cover maps

Thanks to the development of new remote sensing sensors with improved spatial and spectral resolution, various global, regional and local classifications with a spatial resolution of 1 km or even higher exist (Defries and Belward, 2000; Cihlar, 2000; Herold et al., 2007). ECOCLIMAP, for example, is a well-known global land cover product with a spatial resolution of 1 km (Masson et al., 2002). The Global Land Cover (GLC) 2000 classification compiled by JRC and ESA using SPOT-4 remote sensing data also features a spatial resolution of 1 km (Bartholomé and Belward, 2005). As a successor of GLC 2000, GLOBCOVER uses ENVISAT MERIS (Medium Resolution Imaging Spectrometer) fine resolution data (300 m) for mapping the global land cover (Arino et al., 2007; Defourny et al., 2006). The MERIS images used for the GLOBCOVER product were acquired between January 2005 and June 2006 within the frame of the ESA GLOBCOVER project (Bicheron et al., 2008). The data are provided by POSTEL (Pôle d'Observation des Surfaces continentales par TELédétection). These land cover products use different thematic legends but are fully compatible with the LCCS (Land Cover Classification System) used by FAO and UNEP, which comprises 22 different types of land cover (Di Gregorio et al., 2000). As these maps provide global land cover information, they may not necessarily be suitable for regional or local studies. The CORINE Land Cover (CLC) classification is the most detailed regional land cover product available for Europe. It distinguishes 44 classes of land cover with a spatial resolution of 100 m (Heymann et al., 1994; EEA, 2006; Bossard et al., 2000). The data are available for download at the EEA (European Environmental Agency). Many studies comparing the available land cover products e.g. CLC 2000 and GLC 2000 (Neumann et al., 2007; Herold et al., 2007) provide information on applicability and accuracy of the different maps.

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1.2 Heterogeneity of arable land

Energy and matter fluxes are influenced directly by the land surface. Vegetation is a key element for SVAT (Soil-Vegetation-Atmosphere-Transfer) models, regarding its function as an interface between the land surface and the atmosphere (e.g. as a regulator of transpiration) (Monteith and Unsworth, 1990). The land surface has a strong feedback effect to the atmosphere and hence to the climate (Bounoua et al., 2000). Unfortunately most global and regional land cover datasets derived from satellites group croplands into just a few categories, thereby excluding information that is critical for answering key questions of current research (Monfreda et al., 2008; Herold et al., 2007). According to CLC, arable land accounts for 46% of the study area and thereby represents the class with the largest proportion of all land cover classes in Central Europe. However, croplands include a variety of species with different phenology and physiology (Lokupitiya et al., 2009). Exemplarily shown in Fig. 3 for maize and winter wheat based on the temporal development of Leaf Area Index (LAI), the growth cycles of specific crops may differ largely. While the main growth period of winter wheat occurs between May and June, the measurements show that maize grows fastest between July and August. The different phenology not only has an impact on the primary productivity during the growing season but also on the energy fluxes such as latent heat flux, sensible heat flux or long- and shortwave outgoing radiation as well as on CO2 fluxes or soil moisture (Lokupitiya et al., 2009). This must be taken into account when modelling the processes on the land surface. A diverse vegetation phenology within the arable land makes it necessary to split this class into subdivisions of different crop types. Approaches for unmixing cropland out of multitemporal remote sensing data have been carried out successfully using NOAA/AVHRR time series (Probeck et al., 2003). Studies for higher resolution information nevertheless show that amounts of manual interpretation and cloud-free high spatial resolution imagery prohibitive for operational implementation over large areas and in multiple years are required (Lobell and Asner, 2004). However, this approach uses existing land cover products improving them with the help of existing remote sensing products combined with statistical data.

2 Method

2.1 Area of interest

The study area is situated in Central Europe and extends 1170 km north-south by 1170 km east-west including 18 European countries, 6 of them not being members of the European Union (Fig. 1). The landscape is dominated by plains like the Po Valley, uplands like in Central Germany and the Alps that mark a climatic boundary between the temperate latitudes and the Mediterranean climate. Altitudes are ranging from the Mont Blanc in the French Alps (4810 m) to the Atlantic Ocean in the north-west and the Mediterranean Sea in the south. In between, a wide range of different land covers occurs, which are strongly influenced by man. The area is characterized by intense agriculture especially within the fertile lowlands like the Upper Rhine or the Po Valley.

2.2 Hydrological model

The physically based hydrological model PROMET (Processes of Radiation, Mass and Energy Transfer) used in this study to investigate the regional impact of agricultural land informations was developed and validated for the Upper Danube catchment (Mauser and Bach, 2009; Mauser and Schädlich, 1998). The model can be operated on variable scales, but was applied with a spatial resolution of 1 km in this study. Hence, a land use/cover scheme that serves as an input for PROMET at least needs the same spatial resolution. As PROMET uses its own land use/cover parameterization, the nomenclature of the land use/cover classification and the model parameterization have to match. The parameterization scheme in PROMET discerns 27 classes (Table 1) within the first 17 are different types of land occupied by agriculture. The parameterization was created for the watershed of the Upper Danube. The included classes therefore are

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restricted to the regional particularities of the land cover for this region (Ludwig et al., 2003). The motivation for developing a regional land cover map for the larger extent of the area of interest is the need for a detailed description of the European land cover that allows for two-way coupling of PROMET with the regional climate model MM5 (Zabel et al., 2010).

2.3 Land use/cover classification

As this study is concentrating on Central Europe, the CLC 2000 (version 9/2007) classification was well suited for further processing in order to allow for a later use with the PROMET model. Since the 44 CLC 2000 classes do not match the parameterization of vegetation and land cover of PROMET, a transformation from the CLC 2000 classification system to the thematic legend of PROMET was necessary. This was done following the conversion scheme shown in Table 2.

Although the CLC 2000 classes "rice fields", "vineyards", "fruit trees and berry plantations", and "olive groves" are not implemented in the parameterization of PROMET (as they do not exist in the Upper Danube catchment) yet, they were not reclassified to arable land in order to be able to introduce the crop specific parameterization to PROMET at a later point in time.

Since it does not exist within the land cover nomenclature of PROMET, mixed forest was evenly distributed into the coniferous and deciduous forest category using a uniform pattern (Fig. 2).

Since Switzerland is missing within the CLC 2000, the map was completed with the CLC 1990 Switzerland classification having a spatial resolution of 250 m and again using a different nomenclature of land use/cover classification. The transformation of the Swiss land cover classification to the PROMET classes is shown in Table 3.

As Table 3 demonstrates, CLC 1990 Switzerland has a lack of glaciers and no differentiation between coniferous and deciduous forest. The glaciers for Switzerland were added using the GLOBCOVER glacier classification (Bicheron et al., 2008) as a glacier mask for the new classification approach. Furthermore, the Swiss forest was divided

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into coniferous and deciduous forest by using statistical data of the Swiss Federal Statistical Office for each canton (Table 4).

First, all Swiss forested area located at elevations above 1200 m was generally reclassified to coniferous forest according to the following rule.

$$\text{IF DEM} > 1200\,\text{m \&\& Land cover} == \text{“Forest” THEN Land cover} == \text{“Coniferous Forest”} \quad (1)$$

This corresponds to the climatic limit of deciduous forest in Switzerland. The underlying digital elevation model (DEM) used for this decision consisted of 90 m SRTM (Shuttle Radar Topography Mission) data. After the entire forest above 1200 m was identified as coniferous forest, the rest of the forested area was reclassified following the statistical allocation for each canton (Swiss federal Statistical Office, 2004) (Table 4), subtracting the coniferous forested area that has already been classified following rule 1. The sections “mixed coniferous forest” and “mixed deciduous forest” of the statistics each have a fraction of 50–90% of coniferous or deciduous forest respectively but were regarded as unmitigated (100%) coniferous or deciduous forest.

After the modified and reclassified CLC 2000 and CLC 1990 Switzerland were merged to one map, more adaptations were necessary for a subsequent division of the class “Natural Grassland”. In order to meet the regional characteristics of the alpine vegetation, the class “Natural Grassland” was further reclassified to “Rock” or “Alpine Vegetation” based on three assumptions:

$$\begin{aligned}&\text{IF Land cover} == \text{“Natural Grassland” \&\& DEM} > 2400\,\text{m}\\ &\qquad\text{THEN Land cover} == \text{“Rock”}\end{aligned} \quad (2)$$

$$\begin{aligned}&\text{IF Land cover} == \text{“Natural Grassland” \&\& DEM} > 1400\,\text{m \&\& DEM} < 2400\,\text{m}\\ &\qquad\text{THEN Land cover} == \text{“Alpine Vegetation”}\end{aligned} \quad (3)$$

$$\begin{aligned}&\text{IF Land cover} == \text{“Natural Grassland” \&\& slope} > 30\%\\ &\qquad\text{THEN Land cover} == \text{“Rock”}\end{aligned} \quad (4)$$

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Thus, a land cover map for Central Europe was created by merging the CLC and CLC Switzerland into one consistent land cover map and by translating them into the PROMET nomenclature. It further was necessary to divide the arable land into subclasses in order to cover the natural heterogeneity of different crop types in Central Europe. Figure 3 demonstrates the different phenological development of maize and winter wheat, using LAI as example.

The ground based LAI measurements shown in Fig. 3 were collected during a field campaign conducted in Southern Germany (approx. 25 km south-west of the city of Munich), monitoring maize and winter wheat stands during the growing season in 2004. The data points represent values of total LAI, measured by means of the Plant Canopy Analyzer LAI-2000 instrument (LICOR Inc., Lincoln, NE, USA). Each point corresponds to the average of five individual sample points within a winter wheat and a maize stand, respectively. Vertical error bars indicate the observed minimum and maximum within each of the test fields. Although the investigated stands were comparably homogenous and strongly developed, which may cause the absolute values to appear slightly elevated compared to less well developed fields, the general seasonal growth pattern can be considered representative for these crops in Southern Germany. The distinct difference of the temporal dynamics of leaf area accumulation and decrease of wheat and maize accounts well for the characteristic seasonal growth patterns of both crops. While the wheat site was ripening during July and already harvested at the beginning of August, the maize site did not reach its maximum development before the beginning of September. Since the displayed values were derived from non-destructive measurements, only the total LAI of the crops can be considered. If the effect of chlorophyll decomposition during the ripening phase is additionally taken into account, the seasonal disparities between both crops would become even more apparent. Nonetheless, the readings displayed in Fig. 3 clearly indicate that there is a temporal gap in the seasonal behaviour of maize and winter wheat of about 2 months. Bsaibes et al. (2009) showed similar results for temporal dynamics of LAI in Southern France with a temporal shift forward in time of approx. 2 weeks. Those findings support the assumption of this

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typical seasonal behaviour of LAI development for the entire European area of interest.

This context can be transferred to the Normalized Differenced Vegetation Index (NDVI), because of a strong correlation between LAI and NDVI (Baret and Guyot, 1991; Bach 1995). In order to classify the distinct phenological behaviours of different crops according to their photosynthetic activity (maximum LAI/NDVI in spring or summer), a multitemporal NDVI dataset gathered from POSTEL (Pôle d'Observation des Surfaces continentales par TELédétection) was taken into account (Bicheron et al., 2008). With a spatial resolution of 300 m, it provides information about the photosynthetic activity of the vegetation in a two monthly temporal resolution. The dataset can be accessed online free of charge from bimonth 6, 2004 to bimonth 3, 2006 via the POSTEL portal. This approach uses two NDVI scenes of bimonth 3 (May, June) and bimonth 4 (July, August) from the year 2005, since the different photosynthetic activities at these points in time can be used to make assumptions about the type of crop that is growing (Fig. 3). Preparing the data for a change detection approach, bimonth 3 was subtracted from bimonth 4 (Fig. 4). The blue coloured areas in Fig. 4 indicate a phenological behaviour of crops with a photosynthetic maximum in spring while red coloured areas indicate a temporal shift of vegetational activity to summer. Obviously, within the area of interest, significant distinctions in temporal change of NDVI can be made. It is striking that some regions like the northern part of the Po Valley, are clearly distinguished from others.

Using a decision tree as shown in Fig. 5, the change of NDVI, masked with the area of arable land was classified into three different "NDVI-classes".

Detected changes falling below 0.1 were treated as not significant and thus were classified as "equally-active". Changes exceeding 0.1 were classified as "spring-crops" or "summer-crops", respectively.

As a result it is possible to differentiate between the NDVI-classes "spring-crops", "summer-crops" and vegetation that does not show a change in activity within this time period, called "equally active" (Fig. 6). The denotation "summer-crops" groups all kinds of crop plants like maize, potato, sugar beet or legumes that show a phenological be-

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haviour with the highest rate of growth in summer and that significantly exist within the area of interest, while “spring-crops” are e.g. winter wheat, winter barley, rape, oat or rye with highest rates of growth in spring. Regions dominated by “summer-crops” can be recognized e.g. in the Rhine Valley. The Po Valley shows a separation into “summer-crops” north and “spring-crops” south of the Po. Along the Po river, “equally-active” land was classified. While Central Germany, Poland as well as the Czech Republic are mostly covered with “spring-crops”, Hungary, Croatia in the east but also the Netherlands and Belgium in the north-west are mainly covered by “summer-crops”. The resulting map subsequently is used for a further statistical subdivision of these “NDVI-classes”.

This was done with the help of EUROSTAT (Statistical Office of the European Communities) statistical information for each so-called NUTS region (Nomenclature des unités territoriales statistiques) in the area of interest. The NUTS regions represent administrative regions within the countries of the European Union. The EUROSTAT dataset used for this study includes information on the 2006 acreage of different crop types for each NUTS region. The classes “rice”, “vine” and “olives” are already spatially located within the CLC dataset and therefore do not need to be taken into account for the statistical reclassification. A check-up showed that the sum of area of these classes agrees fairly well with the EUROSTAT statistics for each NUTS region. All vegetables of the statistics were merged with the class “fruits and berries”. Therefore, the class label changed to “vegetables, fruits and berries”. Among the other classes, the absolute amount of area associated to each crop type was converted into the percentage of arable land for each NUTS region. Finally, the regional distribution was based on a decision scheme as shown in Table 5. According to the priorities listed in Table 5, the first class to be distributed was winter wheat since it is the most widely spread crop type in Central Europe. As winter wheat is a spring active crop type, it was evenly distributed into the class “spring-crops”. If the spring crop area derived from MERIS was too small to contain all the winter wheat area that should be distributed according to the statistics, the remaining winter wheat areas were further distributed evenly among the

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class "equally-active", according to the "Fill-up-Order" in Table 5. Following the priority of Table 5, the next crop type to be distributed was maize as it is the land use within the arable land occurring second most frequently in the area of interest.

3 Results

3.1 Resulting land use/cover map

In the resulting map, the percentage of each individual class of arable land matches the statistical percentage derived from EUROSTAT for all NUTS regions. However, due to the purely statistical distribution, there is no guarantee for the correct spatial positioning of the pixels. Hence, an accuracy matrix as it is often shown to demonstrate the significance of a land use/cover classification cannot be applied at this point. Nonetheless, the likelihood for a correct placement of a pixel was increased by using the multitemporal NDVI dataset.

Figure 7 shows the resulting land cover map including 18 subclasses of arable land at a spatial resolution of 1 km including the conserved CLC classes "rice", "vine" and "olives". In order to allow for subscale modelling, the same approach was applied for the generation of a 100 m land cover map using CLC (100 m) as base data. In this case, the MERIS NDVI images were resampled from 300 m to the final resolution of 100 m.

The patterns of Fig. 6 still can be recognized in Fig. 7 e.g. in the region of the Rhine Valley that is dominated by maize according to the statistical reclassification. This can be taken as an indication for the reliability of the NDVI approach, since the NUTS statistics well match the NDVI in the Rhine Valley (compare Figs. 6 and 7.). In addition, the segregation within the Po-Valley is reproduced in Fig. 7 in comparison with Fig. 6. Partly, the agricultural areas are fragmented and heterogeneous, due to the applied even distribution method. Due to of a lack of the statistical data for Croatia as well as for Bosnia and Herzegovina, all "summer-crops" in that area were reclassified into maize and all “spring-crops” into winter wheat, while the class “equally-active” was labelled as pasture.

3.2 Impact on latent heat flux

The hydrological impact of the new land cover scheme is shown in the following exemplarily for the Upper Danube catchment. The model PROMET was used for simulating the hydrology using three different land cover schemes as input data.

The first land cover scheme consisted of the reclassified CLC without a subdivision of arable land. Within this land cover scheme, all arable land was reclassified to maize since PROMET is well parameterized for the simulation of this crop type. The second land cover scheme used with PROMET, reclassified the CLC arable land to winter wheat. The third land cover scheme finally consisted of the improved land cover approach mapped in Fig. 5. Investigating the hydrological impact, the evapotranspiration was modelled with PROMET for a time period from 1971–2000. The model was driven by spatially interpolated hourly meteorological data from 277 weather stations (Mauser and Bach, 2009).

Figure 8 shows the simulated mean annual cycle of latent heat flux from 1971 to 2000 as monthly mean values for the Upper Danube catchment. While the annual means of all three runs do not differ much and range from 29.3 to 30.6 W/m^2, the monthly discrepancies are considerable, with up to 18 W/m^2 especially in spring and summer. While the CLC classification with arable land parameterized as winter wheat shows higher monthly mean latent heat flux values than the other land cover schemes from April to June, the CLC classification with arable land parameterized as maize has its maximum in June and a significantly higher latent heat flux till September when it is harvested. Compared to “CLC only maize” and “CLC only winter wheat”, the latent heat flux modelled using the new land cover scheme shows a more averaged course (Fig. 8) as the fractional percentage of spring- and summer crops in this catchment is rather equal.

The difference between the daily mean values of latent heat flux of the three simulations is larger compared to the monthly average. The discrepancies accumulate up to 33 W/m^2 (Fig. 9). The mid summer days, where early and late crops are equally active, result in a phase of transition where the green and the blue line are switching places while the new land use/cover indicated in red represents an average development. Other studies also found significant differences in latent heat flux and other energy fluxes corresponding to different crop types using similar model approaches (Richter and Timmermans, 2009).

4 Conclusions

The changing characteristics of crop phenology in the course of the growing season due to differences in albedo, crop height, aerodynamic properties and leaf and stomata properties affect the energy fluxes on the land surface (Allen et al., 1998). Accordingly, the annual course of the latent heat flux shows a distinct dynamic behaviour. In order to describe these effects in a physical model, a land use/cover scheme is necessary that supplies adequate heterogeneity with high spatial resolution, in combination with an accurate classification and parameterization of its properties. Therefore, in this study we developed a land cover map that uses the high resolution of the CLC classification but comprises the heterogeneity of arable land taking the different phenological behaviour of various crops into account by using remote sensing measurements from ENVISAT MERIS. The importance of land use/cover information is increasing when investigating the interactions between the land surface and the atmosphere (Tian et al., 2004). However, feedback effects from the land surface to the atmosphere are not considered in this study. Vegetation development and land use/cover heterogeneity have a significant influence on climate model simulations such as predictions of surface temperature and precipitation. Thus both, the spatial and temporal distribution of vegetation in climate models is required with a high level of detail (Lu and Shuttleworth, 2002).

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Table 1. PROMET land use/cover classes.

ID	PROMET class	ID	PROMET class	ID	PROMET class
1	Extensive Grassland	10	Potato	19	Residential Built-Up
2	Intensive Grassland	11	Rye	20	Deciduous Forest
3	Silage	12	Setaside	21	Coniferous Forest
4	Forage	13	Sugar Beet	22	Rock
5	Hop	14	Summer Barley	23	Wetland
6	Legumes	15	Summer Wheat	24	Alpine Vegetation
7	Maize	16	Winter Barley	25	Natural Grassland
8	Oat	17	Winter Wheat	26	Glacier
9	Oleaginous	18	Industrial Built-Up	27	Water

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Table 2. Transformation of CORINE Land Cover 2000 into the PROMET classes.

ID	LABEL3		ID	LABEL
1.1.1.	Continuous urban fabric	→	19	Residential Built-Up
1.1.2.	Discontinuous urban fabric	→	19	Residential Built-Up
1.2.1.	Industrial or commercial units	→	18	Industrial Built-Up
1.2.2.	Road and rail networks and associated land	→	18	Industrial Built-Up
1.2.3.	Port areas	→	18	Industrial Built-Up
1.2.4.	Airports	→	18	Industrial Built-Up
1.3.1.	Mineral extraction sites	→	18	Industrial Built-Up
1.3.2.	Dump sites	→	18	Industrial Built-Up
1.3.3.	Construction sites	→	18	Industrial Built-Up
1.4.1.	Green urban areas	→	19	Natural Grassland
1.4.2.	Sport and leisure facilities	→	19	Natural Grassland
2.1.1.	Non-irrigated arable land	→		Arable Land
2.1.2.	Permanently irrigated land	→		Arable Land
2.1.3.	Rice Fields	→		Rice Fields
2.2.1.	Vineyards	→		Vineyards
2.2.2.	Fruit trees & berry plantations	→		Fruit & Berries
2.2.3.	Olive Groves	→		Olive Groves
2.3.1.	Pastures	→		Pastures
2.4.1.	Annual crops associated with permanent crops	→		Arable Land
2.4.2.	Complex cultivation patterns	→		Arable Land
2.4.3.	Land principally occupied by agriculture, with significant areas of natural vegetation	→		Arable Land
2.4.4.	Agro-Forestry areas	→	21	Coniferous Forest
3.1.1.	Broad-leaved Forest	→	20	Deciduous Forest
3.1.2.	Coniferous Forest	→	21	Coniferous Forest
3.1.3.	Mixed Forest	→	20/21	50% Deciduous Forest, 50% Coniferous Forest
3.2.1.	Natural grasslands	→	25	Natural Grassland
3.2.2.	Moors and heathland	→	23	Wetland
3.2.3.	Sclerophyllous vegetation	→	25	Natural Grassland
3.2.4.	Transitional woodland-shrub	→	20	Deciduous Forest
3.3.1.	Beaches, dunes, sands	→	22	Rock
3.3.2.	Bare rocks	→	22	Rock
3.3.3.	Sparsely vegetated areas	→	25	Natural Grassland
3.3.4.	Burnt areas	→	25	Natural Grassland
3.3.5.	Glaciers and perpetual snow	→	26	Glacier
4.1.1.	Inland marshes	→	23	Wetland
4.1.2.	Peat bogs	→	23	Wetland
4.2.1.	Salt marshes	→	23	Wetland
4.2.2.	Salines	→	23	Wetland
4.2.3.	Intertidal flats	→	23	Wetland
5.1.1.	Water courses	→	27	Water
5.1.2.	Water bodies	→	27	Water
5.2.1.	Coastal lagoons	→	27	Water
5.2.2.	Estuaries	→	27	Water
5.2.3.	Sea and ocean	→	27	Water

Table 3. Transformation of the CORINE Land Cover 1990 Switzerland into the PROMET classes.

ID	LABEL1		ID	PROMET-LABEL
11	Urban fabrid	→	19	Residential Built-Up
12	Industrial, commercial and transport units	→	18	Industrial Built-Up
13	Mine, dump and construction sites	→	18	Industrial Built-Up
14	Artificial non-agricultural vegetated areas	→	19	Residential Built-Up
21	Arable land	→		Arable Land
22	Permanent crops	→		Arable Land
23	Pastures	→		Pastures
24	Heterogeneous agricultural areas	→		Arable Land
31	Forests	→	20/21	Deciduous/Coniferous Forest
32	Shrub and/or herbaceous vegetation associations	→	25	Natural Grassland
33	Open spaces with little or no vegetation	→	25	Natural Grassland
41	Inland wetlands	→	23	Wetland
51	Inland waters	→	27	Water

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Table 4. Statistical distribution of coniferous and deciduous forest (km^2) for each Swiss canton (Swiss Federal Statistical Office, 2004).

Canton	Coniferous Forest	Mixed Coniferous Forest	Mixed Deciduous Forest	Deciduous Forest	Total Forest	Not classified
Région lémanique	955	414	278	226	1873	37
Espace Mittelland	1105	856	693	417	3070	80
Nordwestschweiz	108	167	229	149	654	
Zürich	165	143	136	46	489	
Ostschweiz	1708	494	361	231	2794	65
Zentralschweiz	564	327	208	95	1195	19
Tessin	351	189	139	601	1279	26

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Table 5. Priority list and "Fill-up-Order" for the statistical reclassification of "spring-crops", "summer-crops" and "equally-active" crops into 15 different types of arable land.

Priority	Class	Fill-up-Order
	Group: Summer-Crops	
2.	Maize	1. Summer-Crops
3.	Silage	2. Equally-Active
10.	Potato	3. Spring-Crops
11.	Sugar Beet	4. Pastures
15.	Legumes	5. Vegetables, Fruit & Berries
	Group: Spring-Crops	
1.	Winter Wheat	1. Spring-Crops
4.	Winter Barley	2. Equally-Active
9.	Oleaginous	3. Summer-Crops
12.	Oat	4. Pastures
13.	Rye	5. Vegetables, Fruit & Berries
	Group: Grassland	
5.	Extensive Grassland	1. Pastures
6.	Intensive Grassland	2. Equally-Active
7.	Forage	3. Spring-Crops
		4. Summer-Crops
		5. Vegetables, Fruit & Berries
	Group: Set-aside	
8.	Set-aside	1. Equally-Active
		2. Pastures
		3. Summer-Crops
		4. Spring-Crops
		5. Vegetables, Fruit & Berries
	Group: Vegetable, Fruit & Berries	
14	Vegetables, Fruit & Berries	1. Vegetables, Fruit & Berries
		2. Spring-Crops
		3. Equally-Active
		4. Summer-Crops
		5. Pastures

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Fig. 1. Topography (based on SRTM data) of the area of interest, showing the European countries as well as the boundaries of the Upper Danube catchment.

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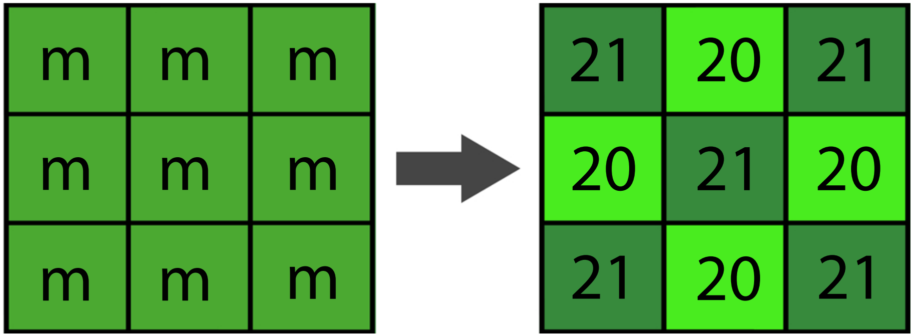

Fig. 2. Reclassification of forested areas labeled as "mixed forest" (m) to an evenly distribution of decidous (20) and coniferous (21) forest. The Pixels are alternately classified to coniferous and decidous.

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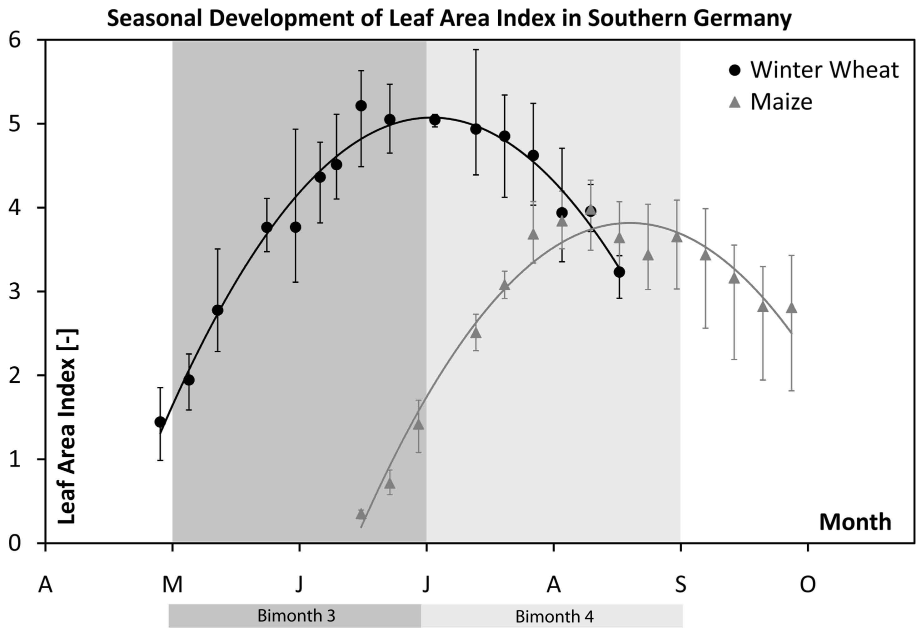

Fig. 3. Seasonal development of LAI for maize and winter wheat for a test side in Southern Germany (April to October 2004). Vertical error bars represent the minimum and maximum observations.

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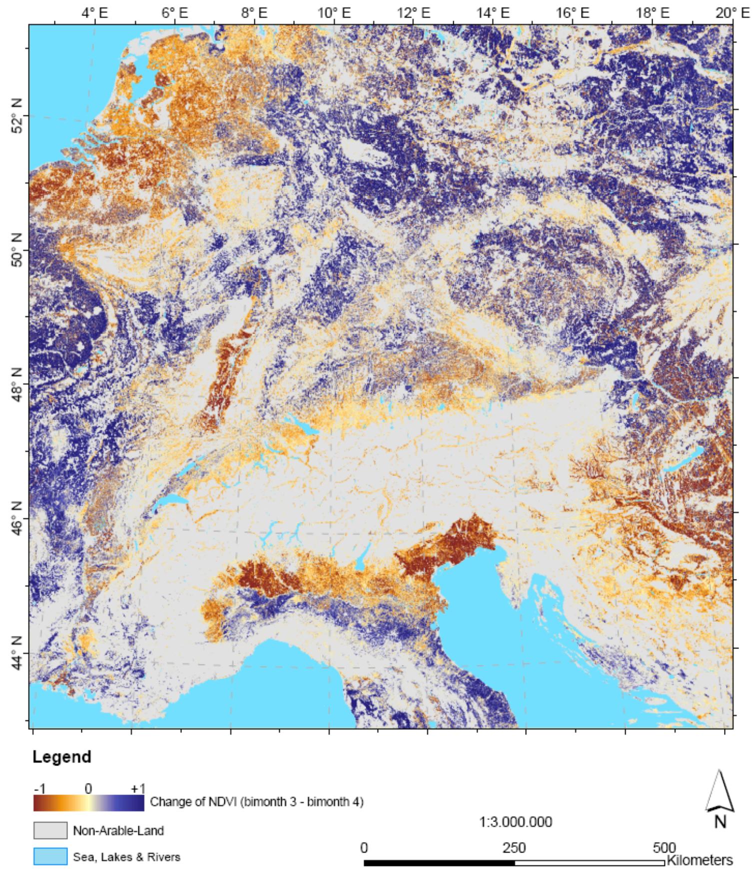

Fig. 4. Temporal change of MERIS NDVI, masked for arable land as a subtraction of bimonth 3 with bimonth 4.

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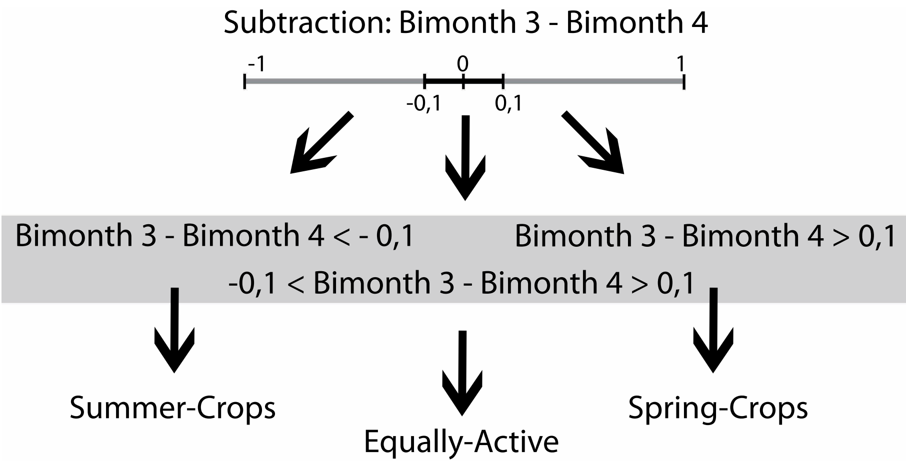

Fig. 5. Decision tree for the differentiation of European maps into three categories of growth activity (spring, summer, equal) using the change signal of two MERIS NDVI images for bimonth 3 and bimonth 4 2005.

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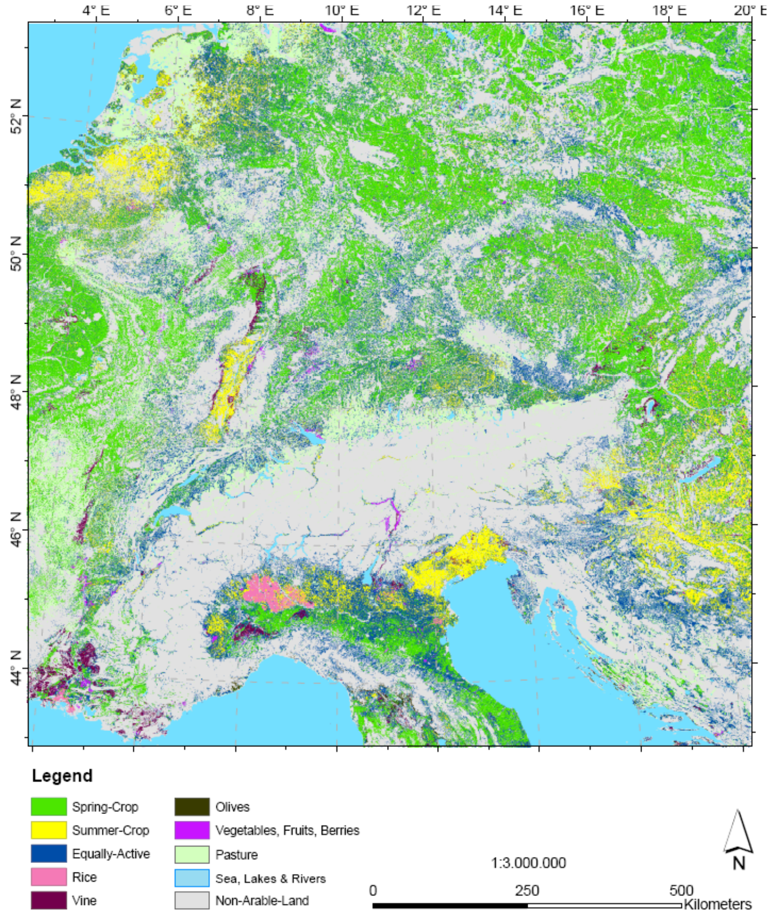

Fig. 6. Phenological subclasses of arable land from CLC after splitting with MERIS NDVI.

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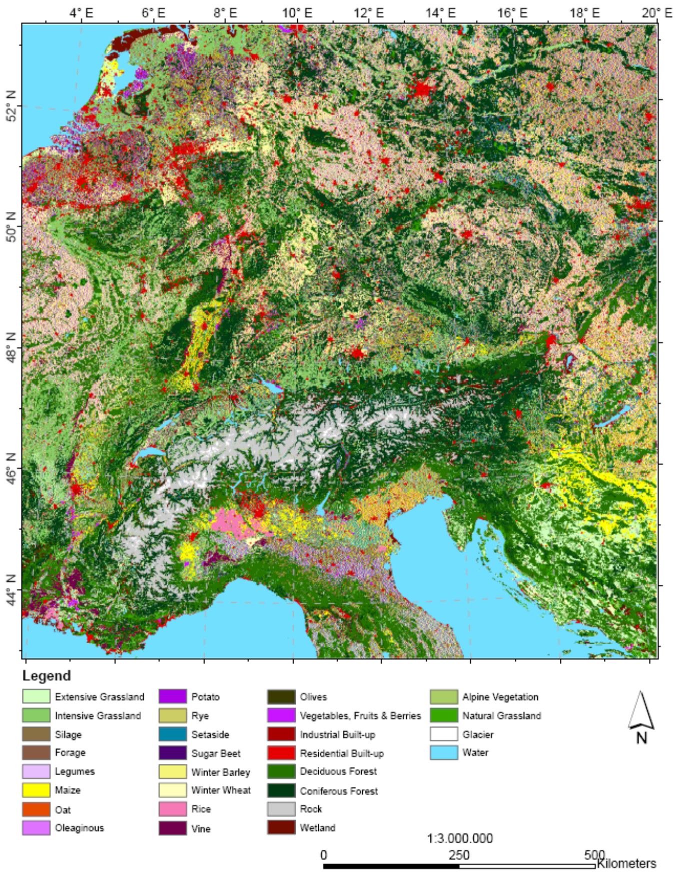

Fig. 7. Resulting land cover map based on CLC and being transformed to the PROMET classification, after phenological subclasses of arable land gathered by MERIS NDVI were further statistically reclassified with the help of the EUROSTAT dataset.

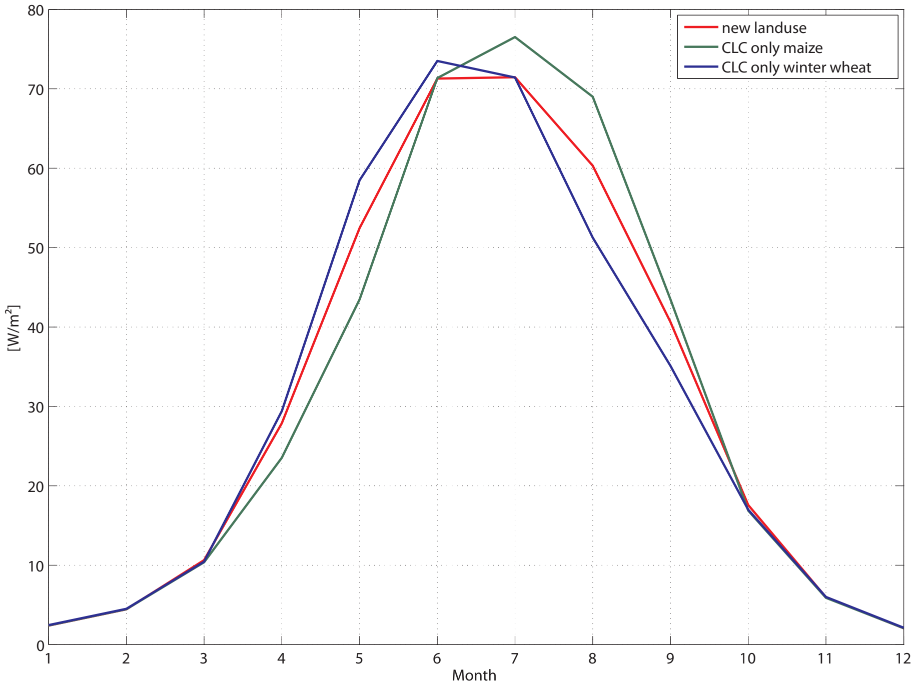

Fig. 8. Monthly mean latent heat flux (W/m^2) of the Upper Danube catchment calculated with PROMET using three different land use/cover classifications (red: new land use approach; green: CLC with arable land parameterized as maize; blue: CLC with arable land parameterized as winter wheat) for the years 1971–2000.

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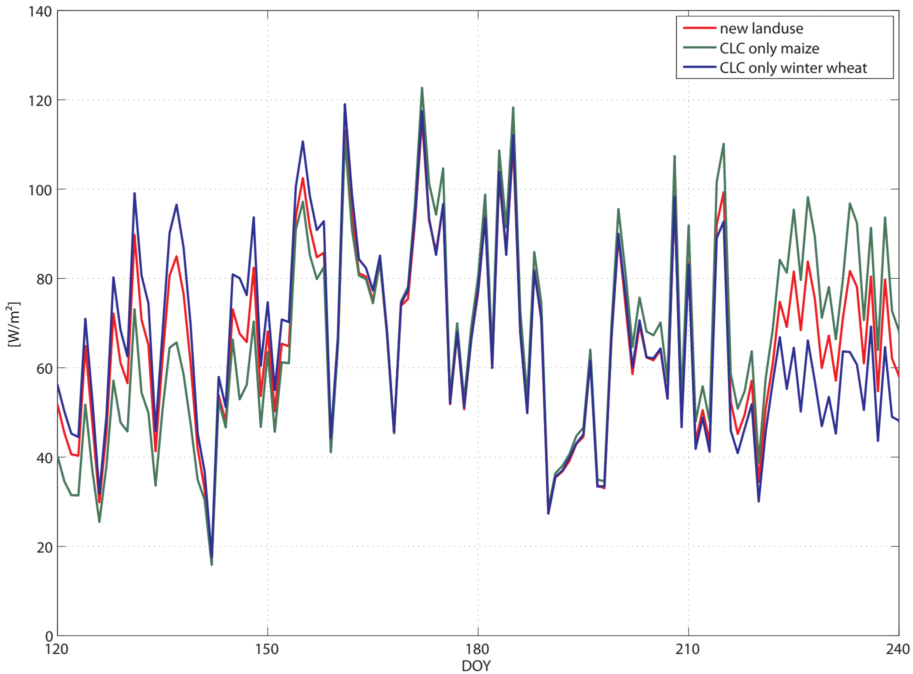

Fig. 9. Daily mean latent heat flux (W/m^2) of the Upper Danube catchment calculated with PROMET using three different land use/cover classifications (red: new land use approach; green: CLC with arable land parameterized as maize; blue: CLC with arable land parameterized as winter wheat) from May–August averaged for the years 1971–2000.

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