New methodologies for grasslands monitoring

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Abstract:

Monitoring grassland areas to assess changes in their condition over time has been the subject of a lot of research at different scales. Initially the techniques focused on field-based measurements, and modelling. However, several obtained data were site specific. Based on the increase in availability of remote sensing data and products, there is an expectation that remote sensing can provide rapid and definite answers to the challenges of detecting and monitoring grassland conditions and associated changes in productivity. At the time of European Copernicus Programme, the new possibilities of satellite data from the group of Sentinel satellites give the new perspective for grasslands monitoring. The Finegrass Polish – Norwegian Project have been set to detect the biomass and its changes for grasslands in Poland and Norway applying different approaches due to different specific of the area. The results have been verified by ground measurements

Key words: grassland, monitoring methods, Corine Land Cover remote sensing, spatial resolution

Introduction

Monitoring of grassland is an activity whereby changes in status of the grassland can be detected and measured through repetitive measurements. This is crucial for the comparison with actual conditions. The most common objectives of botanical monitoring programs are 1/ detection and measurement of natural and man-induced trends; 2/ to study the effects of management practices, thereby allowing an assessment of their suitability (Smith *et al*., 1985). Grasslands have a relatively simple structure compared to many other habitats, with one principal layer of vegetation, usually ranging in height from about 2-100 cm. There may be patches of bare ground and shrub, but for the most part habitat condition is determined primarily by the species composition of the herbaceous sward. There are numerous models for assessing biomass, carbon exchange using meteorological parameters. Monitoring of grassland to assess changes in the condition over time has been the subject of a lot of research at different scales. Initially the techniques focused on field-based measurements, but with the increase in availability of remote sensing products, there is an expectation that remote sensing would provide rapid and definite answers to the challenges of detecting and monitoring grassland conditions and associated changes in productivity.

In this review paper firstly we discuss the importance of grassland monitoring in European perspective in the background of terminology and used methods, then we present the remote sensing application in grassland monitoring in the special focus on the new Polish-Norwegian research project, and finally we conclude with key messages concerning our topic.

Importance of grassland monitoring in European perspective

European grasslands area has been reduced during the last years as a result of intensification of grassland and animal production, decrease in cattle population, use of concentrates and soybean in the ration, abandonment, and the effect of EU-policy (Huyghe *et al*., 2014a), but also areas turned into bioenergy crops including maize. Permanent grasslands cover 33% and temporary grasslands cover 6%, respectively, of the total agricultural areas in Europe and the area vary between countries. To be able to analyze the changes in grasslands in the area and productivity, the constant monitoring of grasslands areas is very important. The productivity of grasslands is affected by several factors such as soil characteristics, climate: amount of rainfall and temperature, latitude, altitude and management. Grasslands contain a substantial amount of the world's soil organic carbon. Integrating data on grassland areas (FAOSTAT, 2009) and grassland soil carbon stocks (Sombroek *et al.*, 1993) results in a global estimate of about 343 billion tonnes of C – nearly 50 percent more than is stored in forests worldwide (FAO, 2007). Just as in the case of forest biomass carbon stocks, grassland soil carbon stocks are susceptible to loss upon conversion to other land uses (Paustian *et al.*, 1997) or following activities that lead to grassland degradation (e.g. overgrazing). Current rates of carbon loss from grassland systems are not well quantified. During the high temperatures in 2003 and 2006, the carbon sequestration decreased substantially in grasslands in Central and Southern Europe, due to reductions in photosynthetic uptake resulting from drought stress (O'Mara, 2012; Reichstein *et al.*, 2007).

Monitoring of grassland in global, biogeographical, country, regional and local scales should focus on grasslands types, areas, productivity and nutrient balances. In the collection of data focusing on grassland resources, monitoring of plant communities is included. The collected information is needed for different purposes, statistical, administrative, scientific and other. For example, monitoring of grassland in European Union is necessary for targeting, monitoring and evaluation of Common Agricultural Policy, environmental policies, climate mitigation targets, High Nature Value farmland, Habitats Directive and Nitrates Directive.

Grassland as a subject of monitoring

Terminology is a key issue in monitoring of grassland.. At the global scale the definition and classification of grassland is a big challenge. Allen *et al.* (2011) carried out a comprehensive study concerning grassland terminology. The authors define the term 'grassland' as synonymous with pastureland when referring to an imposed grazing-land ecosystem. The vegetation of grassland in this context is broadly interpreted to include grasses, legumes and other forbs, and sometimes, woody species may be present. In this term are included temporary, permanent, agriculturally-improved, semi-natural and natural grasslands. The last category is very close to rangeland, meaning land on which the indigenous vegetation (climax or sub-climax) is predominantly grasses, grass-like plants, forbs or shrubs that are grazed or have the potential to be grazed, and which is used as a natural ecosystem for the production of grazing livestock and wildlife. There is still need for better definition and classification of grassland terms, which could improve the present system of data collection and could lead to a better understanding of the importance of diversified grasslands on a global scale and their role in provision of ecosystem services.

Monitoring of biodiversity, also in grassland communities, is increasingly important because the countries are facing difficulties in meeting their reporting obligations under the Convention on Biological Diversity. For habitat monitoring, common field protocols were developed in the last decades and have been brought up to the European level. The core of this habitat monitoring methodology is the system of General Habitat Categories (GHC's). The GHC's may provide the lowest common denominator linking to other sources of data required for assessing biodiversity e.g. phytosociology, birds and butterflies. They may also be more easily discriminated from the air or space using remote sensing methods because the system is based on habitat structure. The approach provides an extremely powerful assessment tool for biodiversity, providing a missing link between detailed site-based species, population and community level measures and extensive assessments of habitats from remote sensing (Bunce *et al*., 2008).

Existing methodologies of grassland productivity estimation

For estimation of grassland productivity, different methods are being used, and in many cases a combination of two and three methods is practicable.

Regular monitoring of land cover in European countries started in 1985 by the Corine program, initiated in the European Union. Corine means 'coordination of information on the environment' and it was a prototype project working on many different environmental issues. The Corine databases and several of its programs have been taken over by the European Environment Agency (EEA). Through the Program, the inventory of land cover in 44 classes, and presented as a cartographic product, at a scale of 1:100 000 has been accomplished applying satellite images on regular basis for Europe. This database is operationally available for most European areas. Updates have been produced in 2000 and 2006, and the latest in 2012. It consists of an inventory Corine Land Cover (CLC) database. The Minimum Mapping Unit (MMU) is 25 hectares (ha). The maps made for 2012 cover Corine Land Cover (CLC) changes 2006-2012. Corine belongs to Copernicus GMES Initial Operation (GIO) Land Monitoring 2011-2013 Programme. The CORINE Land Cover Inventory is the only data set providing a synoptic but broad overview of land cover/land use enabling cross border investigations and comparisons at the European level. In the remote sensing products, like GIO land High Resolution Layers (HRLs), which includes the mapping of five high resolution layers (HRLs) on land cover characteristics, the definition of permanent grassland is necessary (Langanke, 2013). The definition of grassland used in HRL is based on the physical characteristics. “Ground covered by vegetation dominated by grasses and other herbaceous plants”. Grassland includes the following landscape types:

- Pastures, grassland used for grazing or hay production (CLC classes 231, but also appears in classes 211 to 244);
- Cultivated or semi-natural grassland within forest, and grass-covered surfaces within transitional woodland (appears in the context and in the surrounding of CLC classes 311-313, 324);
- Natural grassland in any surrounding (CLC class 321);

- Grassy areas with low fraction (10%) of scattered trees and shrubs;
- Alpine meadows with low fraction (30%) of bare rock or gravel;
- Dehesas, olives, orchards and fruit plantations (when grassy cover fraction is dominant – 70%).

Complexity of grassland monitoring

In the holistic approach of grassland monitoring many characteristics should be collected in different surveying methods: type of grassland (permanent or temporal), land use, yield (t/ha), intensity of exploitation, number of cuts/harvests (times per year), volume of cut grass, grazing status (grazed or not grazed), volume of grazed grass, legal status, other land cover (e.g. percentage of tree and shrub cover), soil type, nitrogen input levels as fertilizer (kg N), species composition, percentage of clover or other N fixing plants, grazing intensity (stocking density), management intensity, manure input levels, ecosystem types, species richness, moisture content/water storage in the soil/groundwater depth, O_2 released/CO_2 fixed, Net Primary Productivity. Most of this information may be described by remote sensing methods

Remote sensing grassland monitoring

There is a need to develop useful tools to monitor the grassland areas exposed to climate changes which affect biomass changes and in consequences changes in greenhouse gases exchange with the atmosphere, K. Dabrowska – Zielinska *et al* 2013; 2014. Remote sensing gives the possibilities to collect spatially, regularly data in optical and radar systems. Regular observations give satellites as Terra and Aqua MODIS, NOAA AVHRR, Landsat 8, SPOT5,6,7; SPOT–VEGETATION (since 2014 PROBA-V). The data are available with different space and time resolution. Data from low spatial resolution satellites as Terra and Aqua MODIS, NOAA AVHRR give information with the one day step. There are also available products within BioPAR of Geoland2 FP7 Project as: Leaf Area Index (LAI), the Fraction of green Vegetation Cover (FCover), the fraction of absorbed photosynthetically active radiation (FAPAR) and the Normalized Differential Vegetation Index (NDVI), Kowalik *et al* 2014. The long-term global biophysical products are important for modeling applications and global change monitoring. A 12-year archive (1999-2011) of these biophysical vegetation products derived from SPOT/VEGETATION sensor, are available and updated every 10 days.

Figure 1 presents the distribution of NDVI over Europe showing the condition of grasslands at the first decade of 2003 from BioPar Product.

Programme Copernicus, previous name GMES, (Global Monitoring Environment and Security) has been set by EU and ESA. New satellites from the group of Sentinel will give regularly data for the whole globe. Sentinel 1 and Sentinel 2 have already been launched in 2014 and 2015. Sentinel 1 with radar has strong potential for monitoring grasslands humidity and Sentinel 2 has 13 spectral bands for monitoring biomass and its changes. Sentinel 3 will be launched in 2015 and will have a thermal channel which will be very useful for monitoring grasslands growth conditions and water balance.

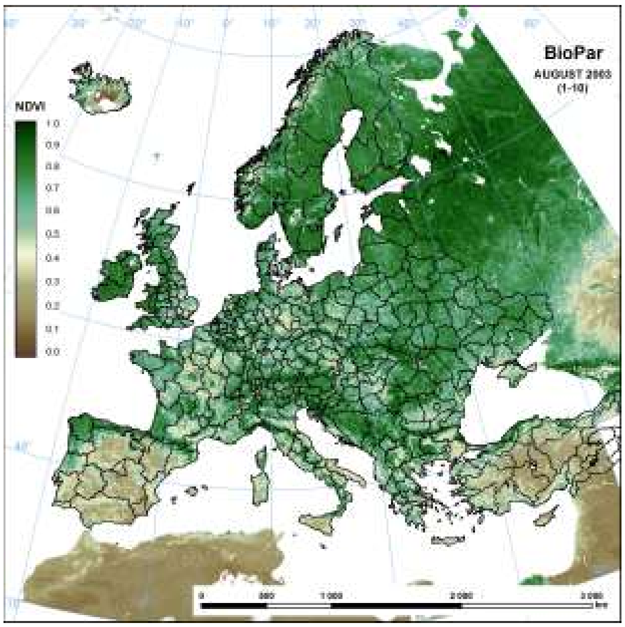

Figure 1 NDVI distribution at the first decade of August 2003 from BioPar Product

Project Finegrass – monitoring of grassland under climate change conditions

The scientific research between Poland and Norway started in 2014 (Dąbrowska-Zielińska *et al 2014)*. The Project : "Effect of climatic changes on grassland growth, its water conditions and biomass" is funded by the Polish-Norwegian Research Programme. The development of methods for grassland monitoring and examining the impact of climatic changes on biomass growth is considered an important tool in grassland management on the national, regional and the individual grassland scale. Remote sensing methods are considered very beneficial for grassland monitoring and management because they may provide extensive information both in time and space, and the existing statistics concerning grassland condition do not provide the necessary information. The prime objective of the Finegrass project is the assessment of the influence of climatic changes on grassland growth, its water conditions, biomass, and subsequently yield.

Thanks to large datasets of phenology observation of vegetation in Norway and also in some sites in Poland, changes or trends in climate can be examined from North Norway to the southern areas in Poland. By undertaking this work on Polish and Norwegian study sites there is the possibility for testing the models over a wide range of climatic and geographic conditions.

Spatial information on ecosystems concerning numerous biophysical parameters and their temporal changes is important for recognition of the state of environment and for determination the direction and cause of its changes. The project research areas are:

- Assessment of impact of climate change on grassland growth conditions in different habitat types (lowland valley, lowland non-valley, mountainous, Central Europe vs. Northern Norway),
- Estimation of the influence of grassland growth conditions on biomass increase, phenology and grassland yield,
- Development of method of grassland yield forecast based on RS data,
- Scientific description of the observed changes in grassland growth and development which influence the methods for management of grassland areas; elaboration of a reasonable model of grassland development and usage in the changing environment,
- Elaboration of the prognosis of environmental effects which are the consequence of a changing environment that affect modification in management of grasslands.

Monitoring grassland in Poland using remote sensing

In Poland, a large area of grassland has been abandoned, and this influences the grasslands ecosystem (Huyghe *et al.* 2014b). By monitoring grasslands area by remote sensing, it is possible to map the abandoned areas and the degree of grasslands degradation and its influence on biodiversity.

There are many standard MODIS data products to be used for monitoring the changes in grasslands as: MODIS Land Surface Temperature and Emissivity; MODIS Land Cover Products; MODIS Vegetation Index Products (NDVI and EVI); MODIS Thermal Anomalies; MODIS Fraction of Photosynthetically Active Radiation (FPAR)/Leaf Area Index(LAI); MODIS Evapotranspiration; MODIS Gross Primary Productivity (GPP) / Net Primary Productivity

(NPP); Albedo Parameter. Gross Primary Productivity and Net Primary Productivity Yearly 1-km (MOD17A3). The goal of the MOD17 MODIS project is to provide continuous estimates of Gross/Net Primary Production (GPP/NPP) across Earth's entire vegetated land surface. MOD17 GPP/NPP outputs are useful for natural resource and land management, global carbon cycle analysis, ecosystem status assessment, and environmental change monitoring. MOD17 is part of the NASA Earth Observation System (EOS) program and is the first satellite-driven dataset to monitor vegetation productivity on a global scale. The Numerical Terradynamic Simulation Group (NTSG) at the University of Montana has set (2000-2006) the MODIS projects on new approaches for landscape ecological and hydrological analyses. The Terra/MODIS Gross Primary Productivity (GPP) product (MOD17A3) is a cumulative composite of GPP values based on the radiation-use efficiency concept that is potentially used as inputs to data models to calculate terrestrial energy, carbon, water cycle processes, and biogeochemistry of vegetation. Net Primary Productivity (NPP) defines the rate at which all plants in an ecosystem produce net useful chemical energy. In other words, NPP is equal to the difference between the rate at which plants in an ecosystem produce useful chemical energy (or GPP), and the rate at which they expend some of that energy for respiration K. Dabrowska – Zielinska *et al* 2010. MOD17A3 is a summation of GPP/ NPP composite at 1-km spatial resolution. The maps of annual GPP and NPP values from the years 2005, 2007 and 2010 for Poland were prepared.

For the year 2005 mean GPP of Poland was 0.95 kgC/m^2 and 0.96 kg/m^2 from grassland areas (based on CLC classes: 231,321). Higher mean annual Gross Primary Productivity was in 2007: 1.04 and 1.06 kgC/m^2 (consecutively). Year 2010 was similar as 2005; 0.97 from the whole country and 0.98 kgC/m^2 from grasslands, Fig 2.

Annual NPP value for 2005 was 0.56 kgC/m^2 from Poland, and 0.57 kgC/m^2 from Polish grasslands. In the 2007 0.61 and 0.63kgC/m^2. For the third observed year (2010) NPP was 0.57 and 0.58 kgC/m^2.

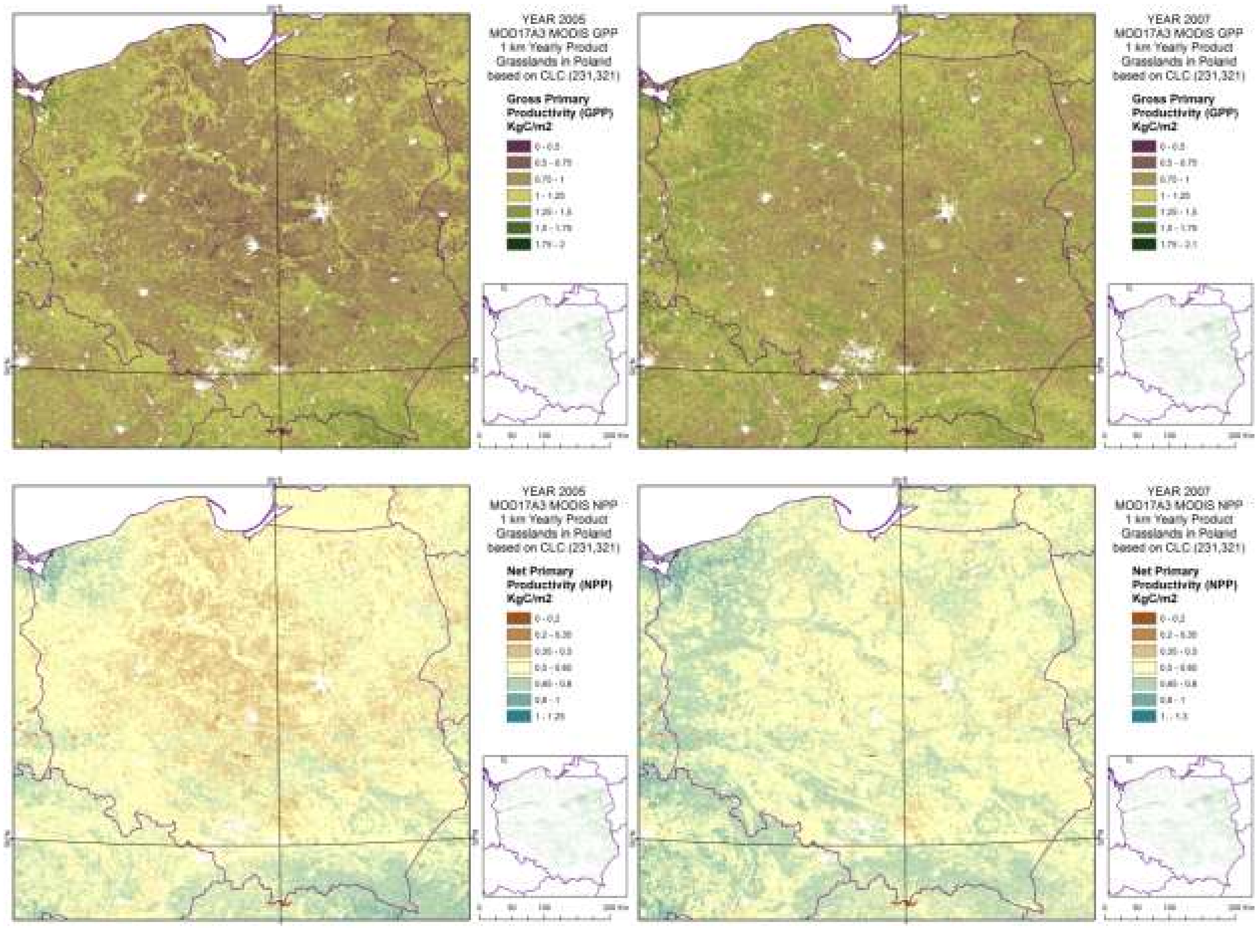

Figure 2 GPP and NPP for 2005 and 2007 for Poland

The MODIS global Leaf Area Index (LAI) and Fraction of Photosynthetically Active Radiation (FPAR) product is composed every 8 days at 1-km resolution on a Sinusoidal grid, Fig 3.

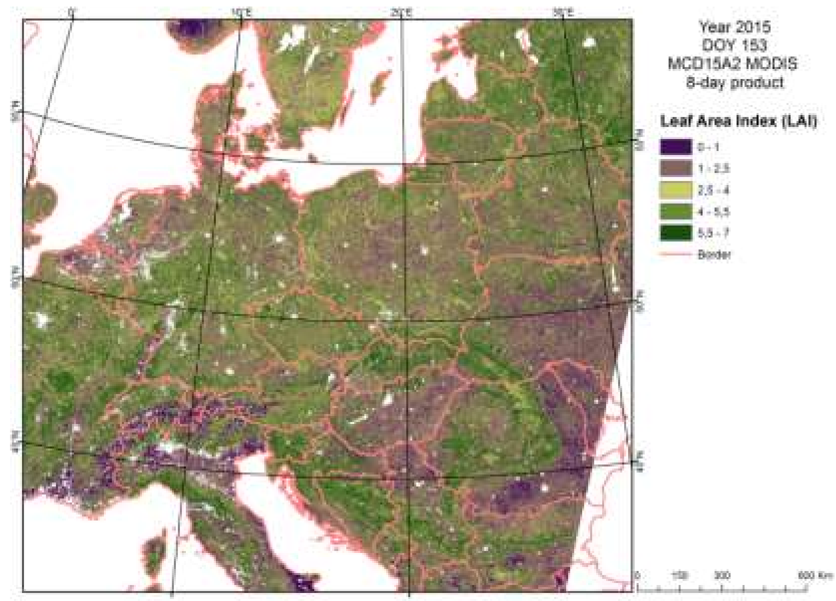

Figure 3. Leaf Area Index for 8-day period (May 2015)

In the Finegrass Project the Corine LC Map has been applied as the data base for Polish grasslands. The Fig 4 presents the Corine Land Cover Map for Poland and the grasslands layer taken from Corine data base.

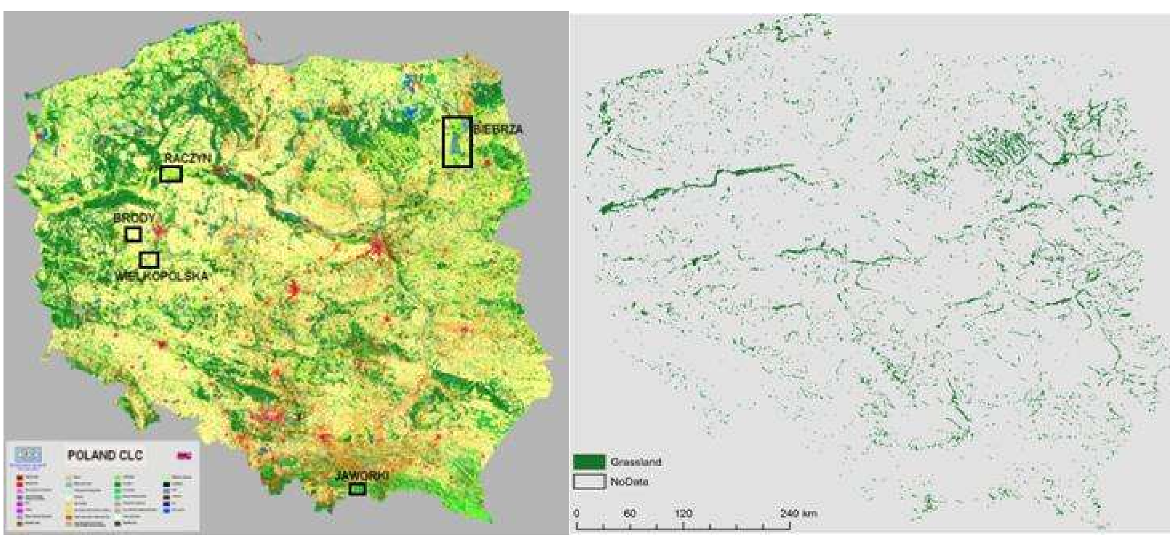

Figure 4. Corine LC Map and Grassland Layer for Poland

The Corine Land Cover 2012 database for Poland is characterized by 31 of 44 classes of CLC. The Minimum Map Unit is 25 ha. At FINEGRASS Project two classes were decided to be used: 231 – Pastures (2460444.1 ha = 8.78%) and 321 - the Natural grasslands as semi-natural land, embrace 0.1% of Poland territory. This class forms the high mountain meadows. It is distributed mainly in the south of Poland. Figure 4 presents the grasslands areas from Corine LC. The CLC Grassland Layer was intersected with AVHRR.NOAA data with resolution of 1000 m to create the grassland-mask. The pixels which characterized the grassland area were these, with the minimum of 50% of grassland (Fig. 4 right). Simultaneously, the MODIS.TERRA image with resolution of 250m was also intersected with CLC Grassland Layer to create a second mask with higher spatial resolution. Resolution of 250m was also intersected with CLC Grassland Layer to create a second mask with higher spatial resolution.

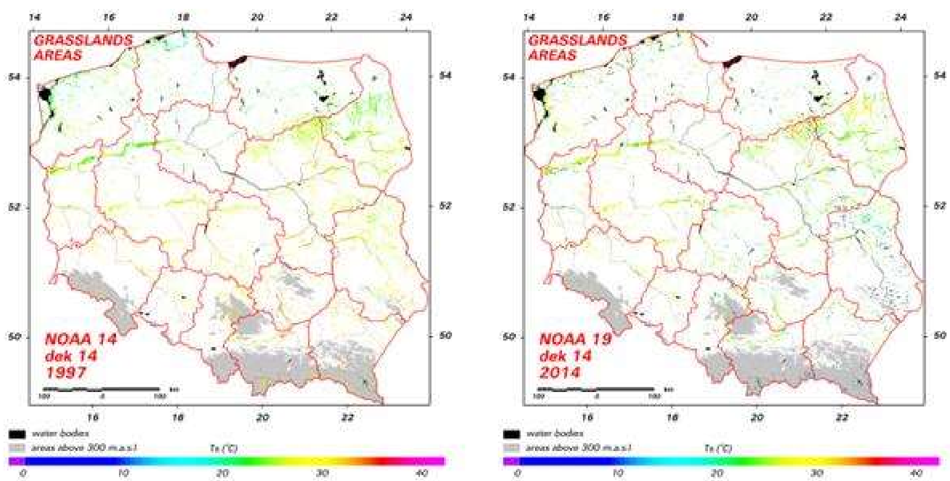

Figure 5 Surface temperatures from NOAA/AVHRR

Applying high temporary satellite data, it is possible to monitor changing conditions at the grasslands area. Figure 5 presents surface temperature at the same decade of the year 1997 and 2014.

Potential of remote sensing of grasslands in Norway

In Norway, cultivated grasslands are characterized by small field sizes. Fields through much of the country are located in narrow lowland regions between the fjords and mountains. In addition, landholdings are small, so these narrow regions are usually divided into many small units among farmers, with field sizes commonly under 1 ha, particularly in northern areas. In addition, due to historical and social reasons and due to somewhat restrictive laws concerning agricultural land sales, grassland fields owned by each farmer are often highly fragmented in Norway. Farmers commonly own and rent several fields that are unconnected, which results in high monetary and time costs to manage these non-adjacent small fields, especially when using heavy machinery, which is the most common practice in Norway.

The agricultural sector in Norway primarily uses remote sensing for creating maps of land use and vegetation types throughout the country. Remote sensing has been used in research on e.g. wheat (e.g. Øvergård et al. 2013) in the country; however it has not been used in grassland research. Remote sensing has significant potential for increased utilization regarding grasslands in Norway.

Agricultural authorities may benefit from using medium spatial resolution satellite imagery (10 – 30m pixels) to monitor severity, extent, and spatial pattern of winterkill (due to winter warming-freezing events), flood, and drought. In addition, intra-annual time series of medium-resolution imagery can be used along with statistical models and existing grassland maps to estimate regional grass yield levels. Inter-annual time series of medium resolution satellite imagery can be used to monitor patterns and extent of field abandonment and re-cultivation for more accurate national statistics.

Farmers may be able to benefit from use of remote sensing to guide field management practices. High-resolution satellite imagery, images taken from unmanned aerial vehicles (UAVs), and handheld spectrometer data can be used in conjunction with ground-truth data in statistical models to estimate field-level yields. Farmers can compare yield and feed quality estimates between fields to assess relative success of various management practices to guide decisions about fertilizer use; how often to sow; when to cut; and which species, species mixes, and varieties to use. Farmers can also use medium-resolution remote sensing images and data to recognize spatial anomalies within their own fields where poor growth areas may lie, information they can use to change management in that part of the field.

Finally, precision agriculture has not yet been practice on grasslands in Norway. Once appropriate statistical models are developed to relate spectral reflectance data to ground-truth data, tractor-mounted spectrometers may be used in grasslands, as is already being used to some extent with grains, to assess need for and apply fertilizer on a micro-level (sub-meter) within each field. Due to the small field sizes of Norwegian cultivated grasslands, low-resolution satellite image data (250m+) is not expected to be very useful for Norwegian grassland agriculture.

In the FINEGRASS project the statistical models to relate grass biomass based to spectral reflectance data has been elaborated. Current models are based on handheld hyperspectral data within the grass fields. Ground-truth data including hyperspectral data has been taken on separate fields in order to build the model and next to verify the usage of Landsat data for biomass. The Partial Least Squares Regression was run to estimate ground-truth biomass from the hyperspectral data. More data are being collected in 2015 for modeling, but preliminary results from the 2014 data show good predictive ability across the three time points: with measured weights between 0 and 100 grams, RMSE for prediction (based on the validation data) was 10 grams with an R^2 of 0.86, and RMSE for cross-validation was also 10 grams with an R^2 of 0.82 (Figure 6).

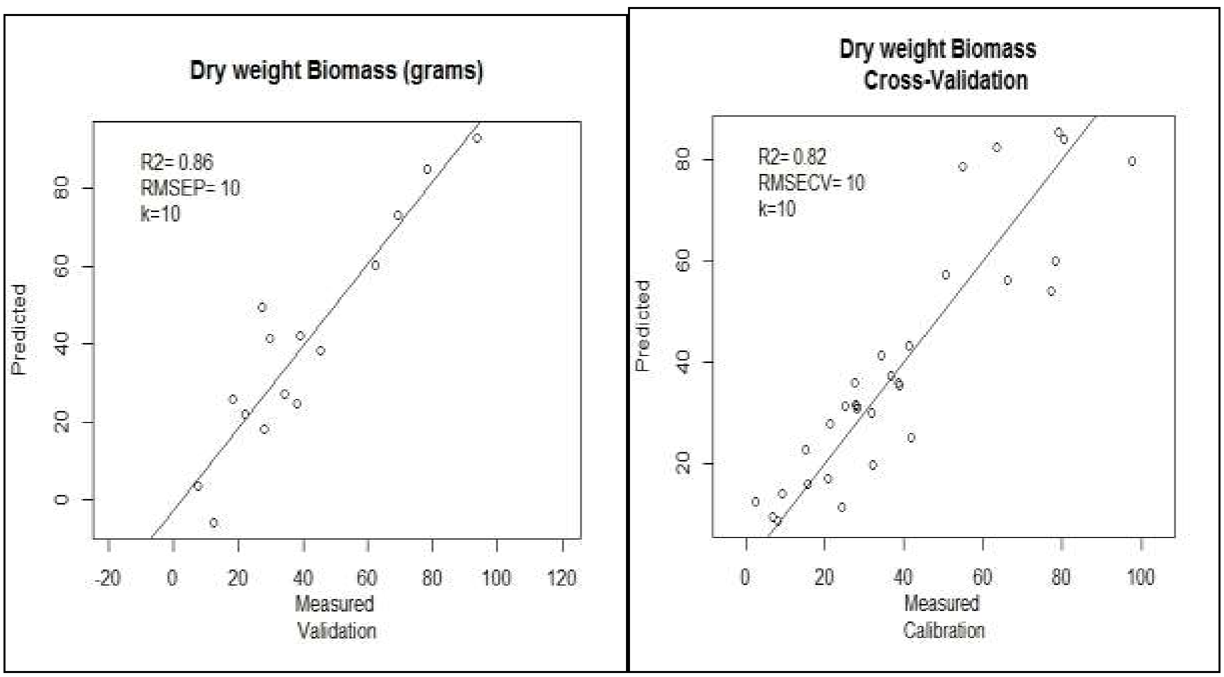

Figure 6. Dry weight biomass predicted and measured

Conclusions

The world is facing climate changes and changes of land use and system of management. These all have different impact on grasslands areas. Due to development and progress in gathering data through remote sensing there is an increasing need to use of newest satellites for regular monitoring the grasslands on regional, European and Global scale. With the launch of Copernicus Programme by EU and ESA and the launch of Sentinel satellites, which will give regular observations of the land in visible, infrared and microwave spectrum, there will be broad information for monitoring of biomass, water cycle, exchange of the energy between the grassland surface and the atmosphere. These possibilities have to be expanded in 2016 for the opportunity of regular monitoring of grasslands.

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