S E S 2 0 1 4
Tenth Anniversary Scientific Conference with International Participation
SPACE, ECOLOGY, SAFETY
12 – 14 November 2014, Sofia, Bulgaria

ESTIMATING LEAF BIOMASS POTENTIAL AS CARBON STOCK IN BROADLEAF FOREST, RHODOPE MOUNTAINS, USING MODIS LAI/ FPAR DATA PRODUCTS

George Letchov

Department of Mathematics Informatics and Physics, Agricultural University of Plovdiv, Bulgaria
e-mail: letchov@outlook.com

Key words: *foliage biomass, broadleaf deciduous forests, Rhodope Mountains, specific leaf area, leaf area index, MODIS, CORINE, ASTER GDEM2*

Abstract: *Despite the fact that the stored carbon in the leaves is only 4% of the total quantity stored in the whole tree (roots, trunk, branches, leaves), the quantities stored on an annual basis are impressive. Annually the stored carbon in deciduous forests in the Rhodopes amounted to 189.9(217.1) Gg, and the CO2 captured in leaves is 696.3(796.2) Gg. The annual production of foliage biomass in the mid-mountain zone of beech and coniferous forests (700-2000 asl.) is about 12% higher compared to that of forests between 0 and 700 m asl. The largest carbon quantities are stored in mixed broadleaf forests of fagus and oak, between 700 and 1200 m.asl. .Annually there are produced between 243.5(251.6) Gg dry foliage mass, 109.6(113.3) Gg stored carbon and 401.7(408.0)Gg CO2 sequestered in the leaves. The results obtained show the importance of accurate measurement of Specific Leaf Area for dominant species, as the error in the estimates can be up to 12%. The estimates are made over territory of 206600ha broad-leaved forests, Rhodope Mountains, using MODIS LAI/FPAR data sets (ESDT: MCD15A2).*

Introduction

Vegetation biomass is a crucial ecological variable for understanding the evolution and potential future changes of the climate system. Vegetation biomass is a larger global store of carbon than the atmosphere, and changes in the amount of vegetation biomass already affect the global atmosphere by being a net source of carbon, and having the potential either to sequester carbon in the future or to become an even larger source [1]. Therefore, assessment of biomass and its dynamics is essential for predicting climate change, mitigating its impact on the environment and developing strategies for adaptation to these changes. International regulations, action plans and standards related to climate changes on regional and global scale, have led to greater need for information on forest carbon stocks. Many tools are available on regional and national levels. The determination of foliage biomass production is very important, and because it allows the evaluation of the total production of biomass using allometric relationships established between the leaf biomass and woody biomass [2] development of carbon estimates from inventory data for multiple forest stands or entire forests is generally an unwieldy process [3]. There are four main ways to monitor biomass: (a) In situ destructive direct biomass measurement; (b) In situ non-destructive biomass estimations (using equations or conversion factors); (c) Inference from remote sensing (experimental stage); (d) Models. Conventional methods (In situ) for forest biomass estimation use existing relations between biomass and bole diameter at breast height. These relationships, however, depend on the type and the region, and so can hardly be applied to larger areas. Using estimates of biomass made by the National Forestry Agencies is not sufficient since they report only the commercially valuable wood rather than all forest biomass [4].

In recent years the vegetation biomass parameters have been directly associated with remotely sensed vegetation indices (VI), such as Landsat TM data and AVHRR Normalized Difference Vegetation Index (NDVI), MODIS LAI/FPAR and from SPOT VEGETATION. Given the need to mitigate the uncertainty in estimates of forest biomass, new spaceborne sensors have been proposed: NASA DESDynI (Deformation, Ecosystem Structure and Dynamics of Ice) mission, ESA BIOMASS mission and JAXA ALOS satellites.

Bulgarian forests have multiple economic, environmental and social functions essential for sustainable development. They are key to the formation and maintenance of the environment and occupy 4.1 million ha or 37.4% of the territory of Bulgaria. Forests provide and maintain the quantity and quality of 85% of the water flow in the country, or around 3.6 billion cubic meters of clear drinking water. Here are over 80% of the protected plant species in the country, over 60% of endangered animal species, eight of the twelve landscape complexes determined by the National Strategy for the Conservation of Biodiversity.

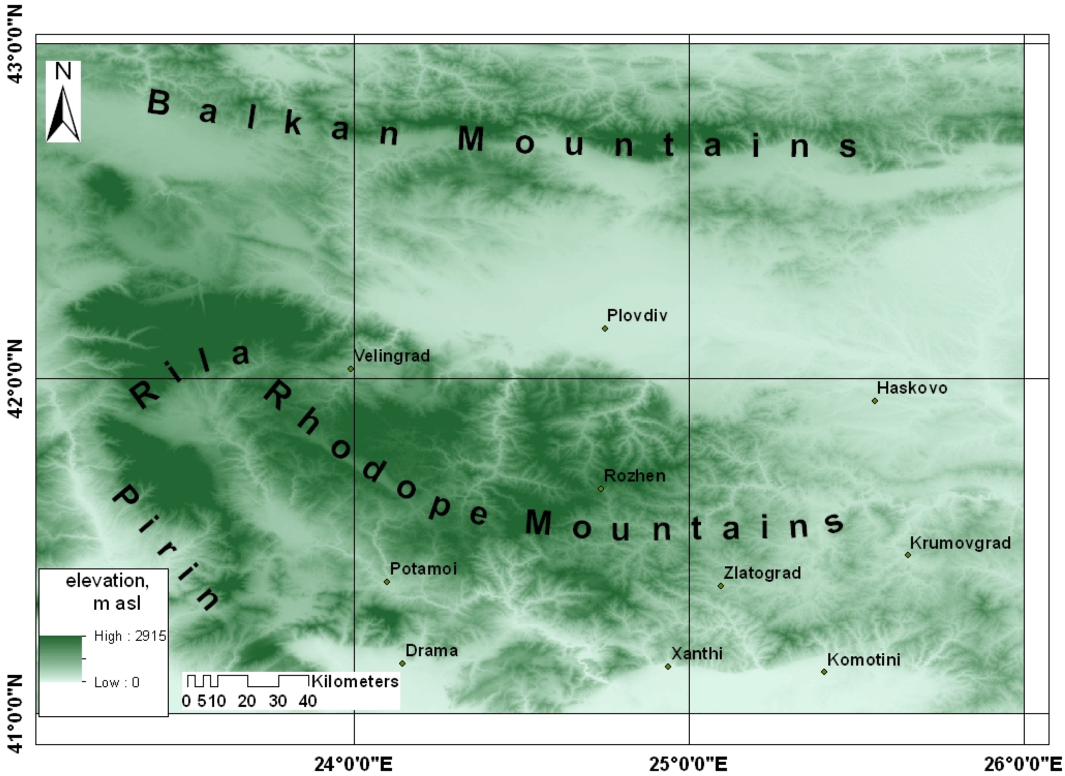

Fig. 1. Rhodope Mountains-Range (Aster GDEM 2)

Foliage biomass is about 3-4% of the above-ground biomass of trees. But annually, the accumulated biomass in the trunk of the tree is comparable to the leaf biomass output. Leaf biomass is a key component in the annual tree litterfall. Apart from being a carbon stock, leaf biomass is a major supplier of nutrients in the soil and increases its fertility and the primary productivity of forest ecosystems. Foliage of some forest tree species contains a large quantity of proteins, starches and fats, making it valuable forage for feeding wildlife.

The present study analyzes the foliage biomass production in deciduous forests of the Rhodope Mountains, based on measurements of leaf area index (LAI) with MODIS spectroradiometer (NASA) on board the Terra and Aqua satellites during 2010. The leaf biomass was calculated using ground measurements of specific leaf area (SLA) of the dominant deciduous species. Tree species were identified using CORINE land cover 2006 data (CLC) and nomenclature, MODIS LAI/FPAR data product and biomes nomenclature, Regional Executive Forest Agency- Plovdiv database, in situ observations and literature data (Greek Rhodpes). CLC data are available at 100 meters resolution and categorized using the 44 classes. Distribution of tree species by altitude is done, combining data from CLC map and higher quality Digital Elevation Model (GDEM2) from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) instrument of the Terra satellite (ASTER GDEM2 is a product of METI and NASA), which represent altitude at 30 meter resolution.

Data and Method

Research area

The Rhodope Mountains are situated in Southeastern Europe, with over 83% of the area in Bulgaria and the remainder in Greece. In Bulgaria, the Rhodope Mountains include large parts of the Thracian Forest Area and South Borderside -Arda subarea (Figure 1). On the territory of Greece, The Rhodope Mountains Range is the second longest after Pindos and it extends from Mt. Falakron and River Nestos in the northeast to the Bulgarian border and the mountainous area of Xanthi. The

Rhodopes are spread over 14,735 square kilometers (5,689 sq mi), of which 12,233 square kilometers (4,723 sq mi) are on Bulgarian territory. The mountains are about 240 kilometers (149 mi) long and about 100 to 120 kilometers (62 to 75 mi) wide. The altitude of the region varies from 300 to 2191 m (Mt Goliam Perelik).

The Rodopi Mountain-Range is highly diverse, both in terms of plant species and vegetation typology. Low elevations (300 - 800 m) are dominated by mixed broadleaf deciduous forests: *Quercus dalechampii T. Ten., Quercus pubescens, Quercus Virgiliana, Carpinus betulus L., Ostrya carpinifolia, Carpinus orientalis Mill., Populus tremula L., Acer pseudoplatanus L., Fraxinus ornus L., Acer platanoides L., Corylus avellana L and evergreen Juniperus oxycedrus*, while at high altitudes (above 800 m asl) *Fagus sylvatica, Pinus sylvestris* and *Picea abies* are dominant.

Foliage mass

Foliage biomass of deciduous forests is found using the relationship between leaf area index-LAI, and specific leaf area SLA:

(1) $$\frac{LAI}{SLA} = \frac{\dfrac{m^2(\text{leaf area})}{m^2(\text{graundf area})}}{\dfrac{m^2(\text{leaf area})}{kg(\text{leaf mass})}} = \frac{kg(\text{leaf mass})}{m^2(\text{graund area})} = LMD$$

Leaf Area Index (LAI) is a dimensionless variable defined as the total one-sided area of green leaves in a vegetation canopy relative to a unit ground area, [LAI] = [m^2m^{-2}]. LAI ignores canopy details such as leaf angle distribution, canopy height or shape. Specific Leaf Area is the one-sided area of a fresh leaf divided by its oven-dry mass, expressed in m^2kg^{-1}. Foliage mass or Phytomass is known also as Leaf Mass Density (LMD) and is measured in [$g.m^{-2}$]. Therefore, to determine the foliage mass, we need data on leaf area index (LAI) and specific leaf area (SLA) for each pixel in the study area.

Leaf area index (LAI) [$m^2.m^{-2}$]

Image data retrieval and processing

The study is based on an analysis of the Leaf Area Index (LAI) – Fraction of Photosynthetically Active Radiation (FPAR) data sets (ESDT: MCD15A2) [5]. The data are composited every 4 days at 1-kilometer resolution by the Moderate Resolution Imaging Spectroradiometer (MODIS) onboard of Tera (EOS AM) and Aqua (EOS PM) satellites, NASA. The MCD15A3 product includes the following Science Data Sets (SDS): LAI, FPAR, and a set of quality rating, and standard deviation layers for each variable.

Leaf area index retrievals algorithm

(1) Data mining from the Hierarchical Data Format [6] database for the studied area. As a result an annual database of 92 images (tiles) is formed containing the LAI data.

(2) Broadleaf forest pixels extract. Based on CORINE land cover 2006 raster data (resolution 100 x 100 m), we retrieved only the pixels classified as Forest and semi natural areas/Forests/Broad-leaved forest- 2066 pixels, each covering an area of $1km^2$ (100ha). Deciduous forests are also present in other CLC classes, as Mixed forest, Heterogeneous agricultural areas, Scrub and/or Herbaceous vegetation associations, but they are not the subject of this study.

(2) Annual LAI time series filtering per pixel to remove data outliers.

(3) Calculation of: LAI_0 – leaf area index during dormancy period DJFM and Leaf Area Index maximum annual value LAI_{max} per pixel. LAI_0 acts as a background component and accounts for evergreen coniferous forest and shrubs.

(5) Then the value of the Leaf Area Index, which we will use to determine the productivity of deciduous broadleaf forest, is

(2) $LAI = LAI_{max} – LAI_0$

Specific leaf area (SLA) [m^2 kg^{-1}]

Specific leaf area, which varies greatly among species and is influenced by environmental conditions [7], is an important leaf characteristic because it is positively related to the net assimilation rate [8]. SLA was measured for the main types of deciduous broad-leaved forests in the region: hornbeam, oak, beech. Samples of 500-600 healthy, fresh leaves of dominant species - oak, hornbeam, beech were collected from 10 plots located at different altitudes from 400 to 1300 m in the period 10 May to 27 July 2011 (see Table 1). Groups of 10-15 leaves were scanned with a high resolution scanner. Software was developed to determine the leaf area of the scanned leaves. Then the leaves are dried for 24 hours at 65^{o}C [9]. Dry leaf mass was measured with an accuracy of 0.01g.

Leaf mass density (LAD) of mixed forest

Much of the deciduous forests in the Rhodope Mountains are mixed: deciduous oak and xerothermic forests (up to 700 m asl), mixed deciduous forests of *Quercus petraea* and *Fagus sylvatica* (between 700 and 1200 m asl). Entirely beech forests occur only above 1200 (1200- 1700 m asl). In the Greek part of the Rhodope the zone of mixed deciduous forest is more blurred and mixed forests of *Quercus petraea*, *Carpinus orientalis*, *Fagus sylvatica* reach 1200- 1300 m asl. Here, *Fagus sylvatica* can be found in the highest parts of the mountains up to 1800 meters asl [10]. Therefore, within a pixel, we can find different plant species and in order to define leaf biomass it is necessary to define Composite SLA per pixel (CSLA). The same problem arises when we want to determine the CO2 sequestered in the leaves.

Let on the territory scanned within the i-th pixel, there be n-forest tree species, each with specific leaf area SLA_k (k=1,n). Then the composite SLA of i-th pixel is

(3) $$CSLA_i = \sum \omega_{ki} SLA_k$$

where ω_{ki} is the part of the area (100ha) occupied by the k-th species in percents. To determine the ω_{ki} we used the distribution of the dominant species in the EFA forest zones and subzones [11] and literature data. Due to the lack of research on the spatial distribution of forest tree species on the Greek territory of the Rhodopes we assume that the stratification of forest species in the Greek part of the Rhodope Mountains is similar to that in the South Borderside -Arda forest subarea.

Then leaf mass density in the i-th pixel- LMD_i, is calculated as

(4) $$LMD_i = \frac{LAI_i}{CSLA_i}$$

As there are no data in the available literature for measurements of the SLA for the less common species, we have worked with data for the three dominant deciduous species of hornbeam, oak and beech. As there are differences between the measured and the average values of the SLA in literature data, we examined three scenarios for calculation of the leaf biomass; Variant 1- measured by us SLA - SLA_1, SLA_2 - data from literature sources and the average of them - SLA_{avrg}

Carbon content

Carbon content in the leaves has been taken from literature [12], for the two main tree groups - the families *Fagaceae* (beech family) and *Betulaceae*(birch family), for a given pixel composite carbon contents has been used, accounting for percentage of species area on the territory covered by a pixel (100ha). The weight of CO_2 sequestrated in the tree was measured from the ratio CO_2 to C which is 3.6663.

Results and Discussion

Specific Leaf Area (SLA)

SLA varies greatly both between the different species and among a given species' representatives (Table 1). The average value of the SLA for beech is 22.07 $m^2.kg^{-1}$, for oak -13.02 $m^2.kg^{-1}$ and for hornbeam 14.82 $m^2.kg^{-1}$. This variability has been registered by other researchers too. Bartelink H. [13] determined that for *Fagus sylavatica the average* SLA value is 17.2 $m^2.kg^{-1}$ and SLA is increasing in the direction from the top of the tree to the base of the crown, at the summit SLA varies between 0.8 and 1.2$m^2.kg^{-1}$ while at the base of the crown it is ~ 30 to 34 $m^2.kg^{-1}$. Castro-Díez J. et al. [14], examined structural reasons for the variation in the leaf mass per unit area (LMA, $g.m^{-2}$) and the variations of the leaf structure on 52 European tree species grown in controlled conditions.

They established that for bushes SLA=20.16 $m^2.kg^{-1}$, (with a ratio of fresh to dry leaf mass FM/DM=*3.57*), for trees SLA = 24.0 $m^2.kg^{-1}$, FM/DM=3.57. For *Fagus sylvatica* SLA=26.8 $m^2.kg^{-1}$, (FM/DM = 2.18). For trees of the genus *Querqus – Q. cerris, Q. petraea, Q. robur* and *Q. suber* they found that SLA=19.2 $m^2.kg^{-1}$ (FM/DM = 2.51).

Meier & Leuschner [15] examined beech forests in southern Saxony, northern Thueringia and southwestern Saxony-anhalt (central Germany). They found that SLA = 21,4 $m^2.kg^{-1}$ (S. E. = 0.48) in 2003 and 19.9 $m^2.kg^{-1}$ (S. E. = 0.52) in 2004. The surveyed sites were located at 300-400m above sea level. The variations of SLA are due primarily to the morphological differences between the leaves situated in direct sunlight and those in shady areas. Davi H. *et al*. [16] established an essential difference between the values of SLA for leaves in the sun and leaves in the shade, SLA = 9.795 m2/kg for leaves in the sun, and for leaves in the shade SLA = 29.87 m2/kg. Bouriaud *at al*. [17] examined SLA on the basis of analysis of beech leaves collected during the autumn leaf-fall. They also established that SLA strongly varied from one location to another, changing from 15.0 to 32.0 $m^2.kg^{-1}$. There is a significant connection between SLA and soil properties. SLA and the leaf area have the lowest values in strongly hydromorphic soils with high nitrogen content. On the other hand, high values of the SLA and the leaf area are observed on soils with low nitrogen content.

Table 1. Specific leaf area (SLA) of the dominant species in the Central Rhodopes

Species	Date	Altitude, m asl	Number, of leaves	FM/DM	SLA, m2/kg dry leaves
Fagus sylavatica	10.5.2011	400-700	519	3.77	25.4194
Fagus sylavatica	15.5.2011	400м	523	2.52	17.0997
Fagus sylavatica	15.5.2011	1000	547	4.45	37.0469
Fagus sylavatica	26.6.2011*	600-1100	540	2.22	15.8634
Fagus sylavatica	27.7.2011*	1000-1300	525	2.32	14.9148
Quercus petraea	10.5.2011	300	534	2.66	8.8982
Quercus petraea	15.5.2011	400-500	630	3.28	16.8190
Quercus petraea	26.6.2011*	400-600	556	1.74	14.8541
Quercus petraea	27.7.2011*	400-500	591	2.11	11.5189
Carpinus betulus	10.5.2011	300-400	597	2.61	14.8196

Note: FM/DM = fresh (FM) /dry (DM) leaf mass.

* Very dry weather. The leaves were picked on south-western slopes and were almost dry

* July was very dry and hot

On the basis of the analysis of the collected literature data: 4 source for Carpinus betulus, 15 sources for *Fagus sylvatica* and 12 for *Querqus*, we can make the following assessments:

Carpinus betulus SLA = 21.925 $m^2.kg^{-1}$

Fagus sylvatica SLA = (21.85 ± 4.65) $m^2.kg^{-1}$ (Confidence Level(95.0%))

Querqus SLA = (13.73 ± 3.85) $m^2.kg^{-1}$ (Confidence Level(95.0%))

Table 2: SLA and Carbon in leaves of dominant species in the region

Family	Species	SLA, $m^2.kg^{-1}$			Carbon*) %
		1-st variant	2-nd variant	average	
Betulaceae	*Carpinus*	21.92	14.82	18.37	46.7
Fagaceae	*Querqus*	13.73	13.02	13.38	44.65
Fagaceae	*Fagus*	21.85	22.07	21.96	44.65

*) Carbon contents in percentage of dry leaf mass

As seen, the results obtained by us for *F. sylvatica* and *Querqus* are close to the average values obtained in the sources above. The SLA obtained by us for *Carpinus betulus* differs from measured by other autors. But it should be noted, that research on the SLA of *Carpinus betulus* are very rare. In order to obtain the quantity of leaf biomass and carbon content in it, we have considered the following three options: 1-st variant our measurements in 2011, 2-nd variant- literature sources [12], average of the two variants

Composite SLA and Carbon mass

To determine distribution of broad-leaved forests with the change of altitude, we have used data from CORINE LAND cover 2006 raster data for the Rhodopes. As seen in Figure 3a, the deciduous forests are concentrated in the 300- 1300m asl zone. Above 1300m they quickly decrease. In this zone are concentrated around 90% of the deciduous forests, the distribution of broad-leaved forest is approximately uniform (between 300m and 1300m). On the basis of these data and the data for identifying and mapping of forest habitat types and the composition of plant communities [11], we have obtained altitude profiles of composed SLA (CSLA) and composite carbon contents in percentage of dry leaf mass.

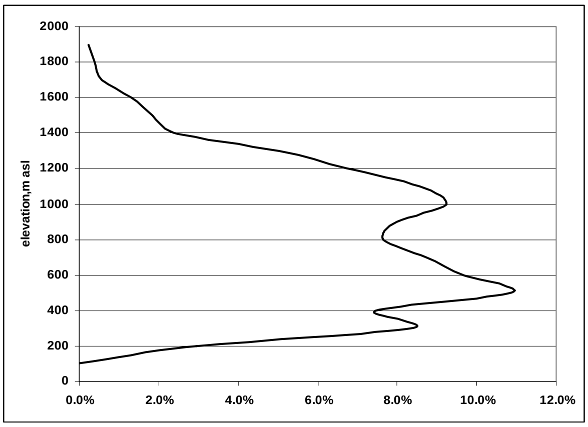

Fig. 3 (a)

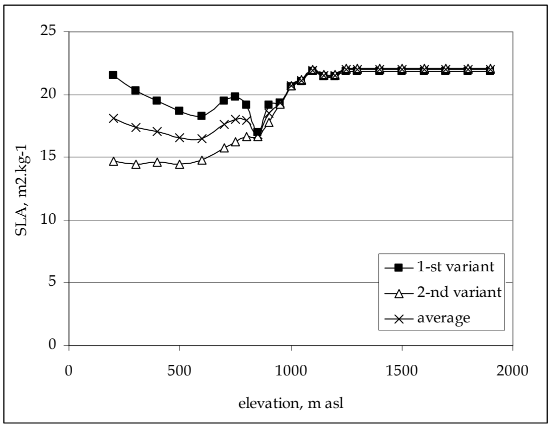

Fig. 3 (b)

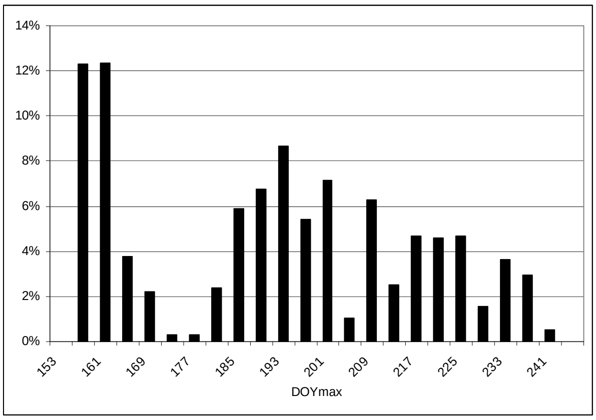

Fig. 4

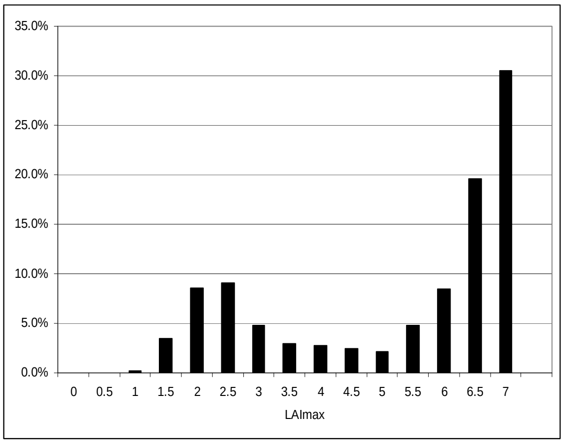

Fig. 5

Figure 3 (a) Broadleaf forest distribution as percentage of total broadleaf forest area; and (b) Composite SLA, (m^2kg^{-1}) with elevation (m, asl) in Rhodope mountains (CORINE land cover 2006).

Figure 4: Frequency distribution of DOY_{max} (2010)- the day of the year in which the deciduous broadleaf forest reaches maximum in the output of leaf biomass..

Figure 5: Frequency distribution of broadleaf LAI_{max}, Rhodopes mountain, 2010.

Here we can see the essential difference from the approach used by NASA MODIS MOD17 product [18] which provides continuous estimates of Gross/Net primary production (GPP/NPP) across entire Earth's vegetated land surface. The MOD17 logic is that biome specific, physiological parameters outlined in the Biome Properties Look-Up Table (BPLUT) within the MOD17 algorithm do not vary with space or time. These biome-specific, properties are not differentiated for different expressions of a given biome, nor are they varied at, any time during the year. For example, if we assume that, SLA is equal to SLA for the dominant species - beech, this would greatly heighten evaluations at the lower forest zones, where *Carpinus* and *Querqus* forests dominate. As can be seen (Figure 3b), CSLA varies strongly in mixed forests, which will affect the estimates of the production of leaf biomass, and the accumulated carbon and CO_2 in forest trees.

Figures 4 and 5 show the frequency distributions of the maximum value of the leaf area index LAI_{max} and the day of the year DOY_{max} in which LAI reaches a maximum. Both distributions outlined the existence of two groups of trees, one is located in the lower parts of the mountain and reach maturity earlier - the middle of June, with maximum values of the leaf area index LAI_{max} from 1.5 to $3.5m^2\ m^{-2}$, while the other is located in the higher parts of the mountain and reach maturity in the interval July - mid August with LAI_{max} over 5.5 m^2 m-^{2}. These, in fact, are characteristics of the Lower planar-hilly-sub-mountain zone of the oak forests and of the middle mountain zone of beech and coniferous forests [11].

When determining the productivity of leafy biomass of broadleaved deciduous forests in the region are considered three variants in terms of SLA (see Table 2). In the first variant is taken the average SLA from literature assessments by other researchers, while in the second variant the average of the values of the SLA from the direct measurements is taken (see Table 1).

Annual foliage biomass productivity for 2010 in the different forest zones and sub-zones is presented in Table 3. The highest productivity is that in mixed forests, located between 700 and 1200 m.asl, where mixed deciduous forests of oak and beech produce on average 2.4 Mg/ha dry leaf mass. This exceeds by 24% to 59% the productivity in the sub-zone of deciduous oak and xerothermic forests (0-500m.). The average productivity of the broad-leaf deciduous forests on the territory of the Rhodopes is 2.14Mg/ha.

In order to assess the accuracy with which leaf mass is determined, we have investigated production of leaf biomass in species-homogeneous forest areas: beech forest (LAI= $5.8m^2.m^{-2}$), oak forest (LAI= 2.5 $m^2.m^{-2}$) and hornbeam forest (LAI= 2.0 $m^2.m^{-2}$). The average productivity of leaf mass of the beech forest is 2.628 Mg.ha-^{1} (2.65 $Mg.ha^{-1}$), that of the oak forest - 1.92 $Mg.ha^{-1}$ (1.82 $Mg.ha^{-1}$), and of the hornbeam forest - 1,34 $Mg.ha^{-1}$ (0.91 $Mg.ha^{-1}$). In brackets are provided assessments for the 2nd variant.

Table 3. Foliage biomass productivity, 2010

Elevation, m asl	Foliage biomass, Mg/ha		
	1-st variant	2-nd variant	Averaged variant
0- 500	1.48	1.98	1.69
500- 700	2.16	2.68	2.39
700-1200	2.35	2.45	2.40
1200-1700	1.99	1.97	1.98
1700-2000	1.98	1.96	1.97
Average	2.01	2.30	2.14

Dimitrova *at al*. [19], studied beech tree communities in the Western Balkan range in three sites - Vitinya, Petrohan 1 and Petrohan 2. They found that the collected litterfall, separated into factions (foliage, branches, trunks), varies from 3.2 to 4.2 $Mg.ha^{-1}$. The leaf litterfall, is: Vitinya 2.80 t.ha-1, Petrohan1 2.51 t.ha-1, Petrohan2 2.70 t.ha-1. As seen the obtained values are close to the estimates obtained for the segment of entirely beech forest, where we have 2.63 $Mg.ha^{-1}$. Blaj & Chifu [20] determined the biomass of 4 forest sites in Romania, formed by *Carpinus betulus*, *Quercus robur* and *Tilia tomentosa*, analysing the results of Romanian and foreign researchers. The sites are located at 300m above sea level, with a northern exposure, 80% of them occupied by *Quercus robur*, *Carpinus betulus* and *Tilia tomentosa*, with average density 670 trees/ha, as the plots with dominant *Carpinus betulus* - 230 trees/ha, *Quercus robur* - 227 trees/ha and *Tilia tomentosa*- 92 trees/ha. Average trunk diameter 25.08cm. The average leaf mass value for *Carpinus betulus* is 1.480$Mg.ha^{-1}$, for *Quercus robur* - 2.017Mg.ha-1, which are close to our estimates.

The annual production of foliage biomass in the mid-mountain zone of beech and coniferous forests (700-2000 asl.) is about 12% (40%) higher compared to that of forests between 0 and 700 m asl (Table 4). The largest leaf biomass quantities are accumulated in mixed forests of oak and hornbeam between 700 and 1200 m.asl. .Annually there are produced between 243.5(251.6) Gg dry foliage mass, 109.6(113.3) Gg stored carbon and 401.7(408.0)Gg CO_2 sequestered in the leaves. Despite the fact that the stored carbon in the leaves is only 4% of the total quantity stored in the whole tree (roots, trunk, branches, leaves), the quantities stored on an annual basis are impressive. Annually the stored carbon in deciduous forests in the Rhodopes amounted to 189.9(217.1) Gg, and the CO_2 captured in leaves is 696.3(796.2) Gg. The results obtained show the importance of accurate measurement of SLA for dominant species, as the error in the estimates can be up to 12%.

Table 4: Distribution of foliage mass production, carbon mass, CO_2 sequestered in leaves in Rhodope Mountains forest zones and sub-zones during 2010.

Elevation m, asl	1st variant*			2nd variant*			Average variant*		
	Foliage Mg	Carbon mass, Mg	CO2 Mg	Foliage Mg	Carbon mass, Mg	CO2 Mg	Foliage Mg	Carbon mass, Mg	CO2 Mg
0- 700	172918	80352	294595	223360	103841	380712	194805	90541	331950
0-500	90303	42229	154826	121166	56683	207818	103438	48380	177375
500-700	82615	38123	139769	102194	47158	172894	91367	42161	154576
700-2000	243491	109575	401734	251645	113313	415440	247231	111290	408021
700-1200	194789	87829	322009	203401	91772	336465	198761	89648	328675
1200-1700	46123	20594	75504	45691	20401	74796	45905	20496	75146
1700-2000	2579	1151	4221	2553	1140	4179	2565	1145	4199
Totals	416409	189927	696329	475004	217154	796152	442036	201830	739971

*) *see Table 2 for definitions of variants*

Conclusions

The present study is the first attempt to use the remote sensing observations of vegetation cover for establishing the ability of the leaves to store atmospheric carbon and thus to reduce atmospheric emissions of CO_2. This will reduce uncertainties in carbon inventory. The results presented here show that MOIDIS LAI / FPAR data products can be successfully used to determine the leaf biomass over large territories, which is very difficult to achieve with ground based measurements. The combination of detailed information on the spatial distribution of forest tree species (CLC) with observations on their development in terms of leaf area index increases the accuracy of estimates of leaf production and storage of atmospheric carbon.

The determination of foliage biomass production is very important, because it allows the evaluation of the total production of biomass using allometric relationships between leaf biomass and woody biomass [2], [21].

Acknowledgements

We would like to thank the various MODIS software development and support teams for the production and distribution of the MODIS data, and making available them to the scientific community.

References:

1. Bombelli, A., V. Avitabile, H. Balzter, L. B. Marchesini, M. Bernoux, M. Brady, R. Hall, M. Hansen, M.Henry, M.Herold, A. Janetos, B. E. Law, R. Manlay, L. G. Marklund, H. Olsson, D. Pandey, M. Saket, C. Schmullius, R. Sessa, Y. E. Shimabukuro, R. Valentini, M. Wulder, (2009). Assessment of the status of the development of the standards for the Terrestrial Essential Climate Variables. Biomass, Global Terrestrial Observing System, version 10, 25 May 2009, Rome
2. Zhang, X. and S. Kondragunta (2006). Estimating forest biomass in the USA using generalized allometric models and MODIS land products. *Geophysical Research Letters*, 33:, L09402, DOI: 10.1029/2006GL025879

3. National inventory report 2011 for Greenhouse Gas Emissions Submission under the UNFCCC and the Kyoto Protocol, Ministry of environment and water, Executive Environment Agency, Republic of Bulgaria (In Bulgarian).
4. Brown, S. L., P. Schroeder, J. Kern. 1999. Spatial distribution of biomass in forests of the eastern USA. *Forest Ecology and Management,* 123: 81-90.
5. Myneni, R,.Y. Knyazikhin, J. Glassy, P. Votava, N. Shabanov (2003). FPAR, LAI (ESDT: MOD15A2) 8-day Composite NASA MODIS Land Algorithm, *User's Guide*
6. The HDF Group (2011). HDF5 User's Guide, *HDF5 Release 1.8.7*.
7. Korner, C.H. (1991). Some often overlooked plant characteristics as determinants of plant growth: a reconsideration. *Functional Ecology*, 5: 162-173.
8. Poorter, H. (1989). Interspecific variation in relation to growth rate: on ecological causes and physiological consequences. In Causes and Consequences of Variation in Growth Rate and Productivity of Higher Plants. Eds. H. Lambers, M.L. Cambridge, H. Konings and T.L. Pons. SPB Academic Publishing, The Hague, pp 45-68.
9. Karlik, J.and A. McKay (2002). Leaf Area Index, Leaf Mass Density, and Allometric Relationships Derived From Harvest of Blue Oaks in a California Oak Savanna, *USDA Forest Service Gen. Tech. Rep. PSW-GTR-184*.
10. Tsiripidis I.and N. Athanasiadis (2003). Contribution to the knowledge of the vascular flora of NE Greece: Floristic composition of the beech (*Fagus sylvatica* L.) forests in the Greek Rodopi, *Willdenowia* 33: 273-297.
11. Executive Forest Agency, (2011). Instructions for identifying and mapping of the location types and the composition of tree associations. Second Edition Publisher: Bulprofor, Sofia 2011, ISBN: 978-954-9311-09-9 (in Bulgarian)
12. Vergutz, L., S. Manzoni, A. Porporato, R.F. Novais, and R.B. Jackson (2012). A Global Database of Carbon and Nutrient Concentrations of Green and Senesced Leaves. Data set. Available on-line [http://daac.ornl.gov] from Oak Ridge National Laboratory Distributed Active Archive Center, Oak Ridge, Tennessee, U.S.A.
13. Bartelink, H.,(1997). Allometric relationships for biomass and leaf area of beech (*Fagus sylvatica* L), *Annals of Forest Science*, 54: 39-50.
14. Castro-Díez P., J. Puyravaud J. Cornelissen (2000). Leaf structure and anatomy as related to leaf mass per area variation in seedlings of a wide range of woody plant species and types, *Oecologia,* 124: 476–486.
15. Meier, I. C. and C. Leuschner (2008). Leaf Size and Leaf Area Index in Fagus sylvatica Forests: Competing Effects of Precipitation, Temperature, and Nitrogen Availability, Ecosystems (2008) 11: 655–669
16. Davi, H., C. Barbaroux, E. Dufrêne, C. François, P. Montpied, N. Bréda, F. Badeck (2008). Modelling leaf mass per area in forest canopy as affected by prevailing radiation conditions, *Ecological Modelling,* 211: 339–349.
17. Bouriaud, O., K. Soudani, N. Bréda (2003). Leaf area index from litter collection impact of specific leaf area variability within a beech stand, *Canadian Journal of Remote Sensing*, 29 (3): 371–380.
18. MODIS Land Team (2003). GPP and NPP (MOD17A2/A3) Products. NASA MODIS Land Algorithm. *User's Guide*.
19. Dimitrova, V., M. Lyubenova, K. Slavova (2009). Investigation of some functional parameters of the beech (Fagus Sylvatica L.) communities. *Journal of Biotechnology & Biotechnological Equipment,* SE, 23, 426-429
20. Blaj, I. And T. Chifu (2004). Biomass and the aerial productivity of the arborescent layer of the Aro Orientalis-Carpinetum (Dobrescu Et Kovacs 1973) Täuber 1991-1992 association from the Vaslui river basin. *Buletinul Grădinii Botanice Iaşi*, 12 (45-51),
21. Widlowski, J., M. Verstraete, B. Pinty, N. Gobron (2003). Allometric Relationships of Selected European Tree Species. Parametrizations of tree architecture for the purpose of 3-D canopy reflectance models used in the interpretation of remote sensing data. EUR 20855 EN, Science & Technology, EC Joint Research Centre, Ispra (VA), Italy