Implementing Multi-scale AGricultural Indicators Exploiting Sentinels

VALIDATION REPORT FOR THE LAND DATA ASSIMILATION SYSTEM OPERATED BY OMSZ

IMAGINES_RP7.4_Validation-LDAS

ISSUE I1.10

EC Proposal Reference N° FP7-311766

Due date of deliverable: 30.06.2015

Actual submission date: 31.07.2015

Start date of project: 01.11.2012 Duration : 40 months

Name of lead partner for this deliverable: OMSZ

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Project co-funded by the European Commission within the Seventh Framework Program (2013-2017)		
Dissemination Level		
PU	Public	**X**
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

DOCUMENT RELEASE SHEET

Book Captain:	H. Toth	Date: 05.05.2016	Sign. Helga Toth
Approval:	R. Lacaze	Date: 18.05.2016	Sign.
Endorsement:	M. Koleva	Date:	Sign.
Distribution:	Public		

CHANGE RECORD

Issue/Revision	Date	Page(s)	Description of Change	Release
	12.10.2015	All	First issue	I1.00
I1.00	05.05.2016	8-25	Update of the report. rescaling of ASCAT SSM, LDAS rerun with rescaled data	I1.10

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ACRONYMS

ASCAT (Advanced Scatterometer)

AST (ISBA model option with net assimilation of CO_2, enhanced soil water stress representation, but without vegetation evolution)

ATBD (Algorithm Theoretical Basis Document)

EKF (Extended Kalman filter)

ELTE (Eötvös Loránd Tudomány Egyetem – Eotvos Lorand University)

ET (evapo-transpiration)

GEOV1 (Version 1 of LAI, FAPAR, FCover products)

GPP: (Gross Primary Product)

ISBA-A-gs (Interactions between Soil, Biosphere, and Atmosphere, CO_2 responsive)

LAI (Leaf Area Index)

LDAS (Land data assimilation system)

LSM (Land Surface Model)

MARS (Monitoring Agricultural ResourceS)

NEE (Net Ecosystem Exchange)

NIT (ISBA model option with net assimilation of CO_2, enhanced soil water stress representation, and vegetation evolution, including nitrogen dilution)

RMSE (Root Mean Square Error)

SAFRAN (Système d'Analyse Fournissant des Renseignements Atmosphériques à la Neige)

SIM (SAFRAN-ISBA-MODCOU)

SSM (Surface soil moisture)

SURFEX (Externalized surface)

SWI (Soil Water Index)

VEGETATION (The medium resolution sensor onboard SPOT4 and SPOT5)

WOFOST (WOrld FOod STudies)

1 BACKGROUND OF THE DOCUMENT

1.1 EXECUTIVE SUMMARY

The main objectives of ImagineS are to (i) improve the retrieval of basic biophysical variables, mainly LAI, FAPAR and the surface albedo, identified as Terrestrial Essential Climate Variables, by merging the information coming from different sensors ‘PROBA-V and Landsat-8) in view to prepare the use of Sentinel missions data; (ii) develop qualified software able to process multi-sensor data at the global scale on a fully automatic basis; (iii) explore new paths to complement and contribute to the existing or future agricultural services by providing new data streams relying upon an original method to assess the above-ground biomass, based on the assimilation of satellite products in a Land Data Assimilation System (LDAS) to monitor the crop/fodder biomass production together with the carbon and water fluxes; (iv) demonstrate the added value of this contribution for a community of users acting at global, European, national, and regional scales.

The land data assimilation system (LDAS) developed in the SURFEX modeling platform permits the joint assimilation of remotely sensed Surface Soil Moisture (SSM) derived from ASCAT backscatter data and the GEOV1 satellite-based LAI into the ISBA-A-gs land surface model. The ASCAT data are bias corrected with respect to the model climatology by using a seasonal-based CDF (Cumulative Distribution Function) matching technique. A multivariate multi-scale LDAS based on the Extended Kalman Filter (EKF) technique is used for monitoring soil moisture, vegetation, and terrestrial surface carbon and energy fluxes across the Hungarian domain at a spatial resolution of 8 km. Each model grid box is divided in a number of land covers, each having its own set of prognostic variables. The filter algorithm is designed to provide a distinct analysis for each land cover while using one observation per grid box. The updated values are aggregated by computing the weighted average.

A validation methodology was implemented and focused on above-ground biomass, LAI, SWI, root zone soil moisture and water- and CO_2 fluxes. Open-loop (SURFEX run without assimilation) and LDAS (assimilated of GEOV1 LAI and SWI) runs were compared each other and against the satellite measurements (GEOV1 LAI and SWI) and in situ data collected at Hegyhatsal site. The added value of the assimilation of satellite products on vegetation biomass simulations is evaluated over Hungary using reference agricultural yearly statistics of straw cereal yields. It is shown that a significant improvement is obtained by using the LDAS chain.

1.2 Scope and Objectives

On one hand, 1D and 2D evaluation is performed to validate the LDAS-Hungary chain operated by OMSZ. On the other hand, in situ agricultural observations over Hungary are used. In addition, simulations from the WOFOST crop model are used as a benchmark.

1.3 Content of the Document

Chapter 2 presents the 1D and 2D validation of the LDAS products. In this chapter the validation framework of the LDAS for agriculture is also shown. Conclusions and prospects are presented in Chapter 3.

1.4 Related Documents

1.4.1 Inputs

Overview of former deliverables acting as inputs to this document.

Document ID	**Descriptor**
ImagineS_RP1.1	Users Requirements Document
ImagineS_RP1.2	Service Specifications Document
ImagineS_RP3.1	LDAS ATBD

1.4.2 Output

Overview of other deliverables for which this document is an input:

Document ID	**Descriptor**
ImagineS_RP6.3	Product User Manual of LDAS output products

2 VALIDATION FRAMEWORK

2.1 INTRODUCTION

The possibility of improving the performance of land surface models (LSMs) using remotely sensed observations is a field of active research. The mechanism of integrating observations, in a statistically optimal way, into a numerical model is called “data assimilation”. The latter permits improving the representation of the dynamical behavior of a bio-geophysical system. Land data assimilation systems (LDAS) are needed to integrate satellite data providing information about land state variables such as the surface soil moisture (SSM) and leaf area index (LAI) into LSMs.

Soil moisture is a key factor controlling both the water and energy cycles (through its impact on the fluxes partitioning at the surface). In addition, it is linked to the carbon cycle through the coupling between plant transpiration and photosynthesis. A number of studies have discussed the importance of soil moisture in the description of the carbon cycle whose connections with the hydrological cycle are largely unknown (van der Molen et al., 2011). Assimilating remotely sensed SSM data into a LSM has proved, in a large number of papers, to be effective in estimating deeper soil moisture in various contexts, such as hydrology (Houser et al., 1998; Reichle et al., 2002; Draper et al., 2011), numerical weather prediction (NWP) (Mahfouf, 2010; Dharssi et al., 2011; de Rosnay et al., 2013) and agricultural studies (Bolten and Crow, 2012).

Also, LAI impacts the exchanges of water vapor and CO_2 between the vegetation canopy and the atmosphere. A number of studies (Jarlan et al., 2008, Gu et al., 2006, Demarty et al., 2007) have shown the potential of assimilating LAI observations to correct vegetation model states.

Barbu et al. (2014) have shown that the LDAS is able to: (1) simultaneously ingest EO satellite data providing mixed signals at a grid-scale into the mosaic structure of the ISBA-A-gs LSM (Calvet et al. 1998) within SURFEX (Masson et al. 2013); (2) propagate information from the surface into the root-zone soil layer; (3) consistently impact the water and carbon fluxes; (4) improve the short-term vegetation response to drought conditions.

The scientific validation of the products aims to assess the reliability (spatial and temporal) of the products, determine accuracy and precision of the products, identify problematic areas and possible cause of errors, analyze the compliance regarding users requirements, and provide recommendations on the usability of the products. It has been shown that the above-ground biomass simulated by ISBA-A-gs over croplands and grasslands relates to agricultural yields (Calvet et al. 2012), especially for grasslands; this finding indicates that the model could be used to produce new drought indicators useful for agricultural yield monitoring and this will be investigated over France.

ISBA-A-gs forms the basis of a Land Data Assimilation System (LDAS), able to ingest satellite-derived products (LAI, surface soil moisture) at a spatial resolution of 8km over Hungary. The LDAS Hungary validation focuses on 1D and 2D evaluation of the main model outputs.

2.2 1D VALIDATION (AGAINST MEASUREMENTS OF HEGYHATSAL)

1D validation of the results is performed against in-situ measurements of Hegyhatsal. This grassland site is operated by the Eötvös Loránd University (ELTE), which is a sub-contractor of OMSZ in the ImagineS project. In the framework of this sub-contract, ELTE provides in-situ measurements to validate LDAS simulations.

Hegyhatsal is a FLUXNET site, which is located in a flat region of western Hungary, surrounded by agricultural fields and forest patches (Figure 1). The TV and radio transmitter tower (owned by Antenna Hungária Corp.) is located in a flat region of western Hungary (46°57'21''N, 16°39'08''E), at an altitude of 248 m above sea level, near Hegyhatsal. The tower is also a NOAA/CMDL global air sampling network site. Measurements of CO_2 mixing ratio profiles, temperature, humidity and wind profiles began in September 1994. Flux measurements began in April 1997. The eddy covariance system is operated at 82 m and 3 m height. Small villages are located within 10 km of the tower, the nearest village being Hegyhatsal about 1 km to the northwest. No notable industrial activity in the area, low levels of traffic (http://fluxnet.ornl.gov/site/505). According to Ecoclimap II database (Faroux et al., 2013), the rate of grassland is 23%, C3 plants are 33%, C4 plants are 5% and deciduous forest is 16% in point of Hegyhatsal.

Simulated carbon- and water fluxes (assimilation and open-loop runs) are evaluated over the grassland patch and over the whole tile. The results from the grassland patch are compared to the in-situ observations from 3 m height. The simulated mean values (averaged by the patch fractions) are validated against the in-situ measurements form 82 m height, because it is supposed that the simulated and observed products are valid for the whole tile.

Figure 1: Hungary and location of Hegyhatsal

2.2.1 Leaf Area Index

The Leaf Area Index measurements are collected from a grassland area. It is measured weekly during the growing season with Decagon AccuPAR LP-80 PAR/LAI Ceptometer. Evaluation of LAI is presented below for 2010 (Figure 2) and 2013 (Figure 3). The solid lines (purple - assimilation and green – open-loop) indicate the simulated LAI values at grassland patch, which is the 10. patch (10p) in SURFEX. It can be seen that the satellite measurements (red points) are extremely far from the in-situ data (blue points with error bars) and both experiments (open-loop (green) and assimilation (purple)) more or less follow the satellite values (SPOT/VGT LAI known as GEOV1 provided by the Copernicus Global Land service). The impact of the assimilation can be traced in Figure 3, wherein the simulated LAI derived from LDAS follows the satellite measurements as saw-tooth.

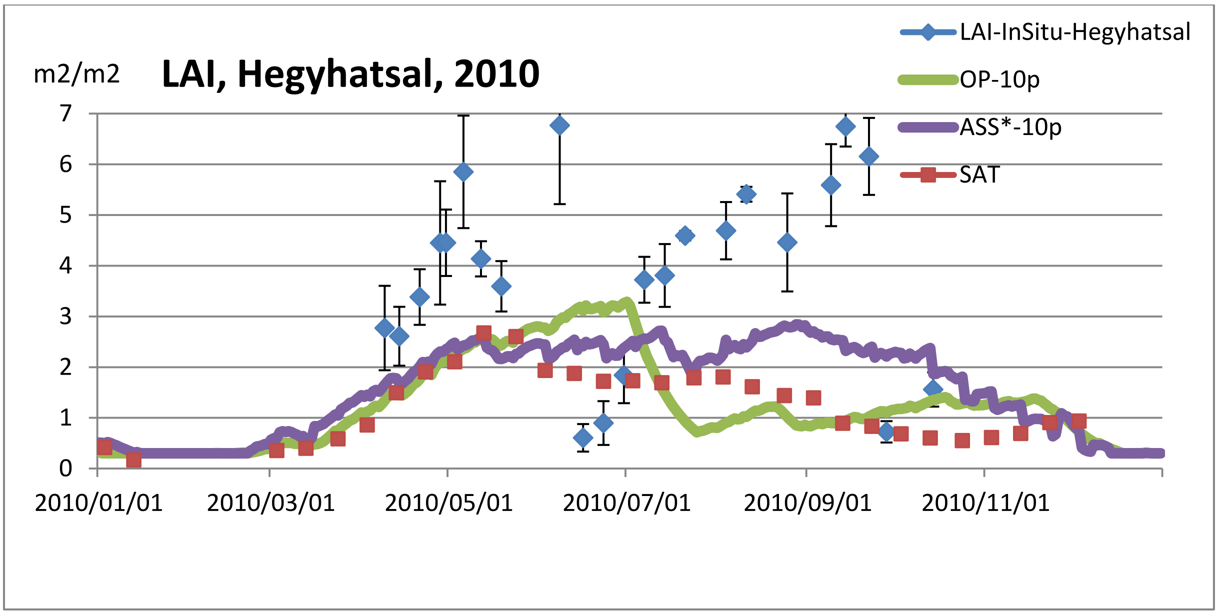


Figure 2: LAI in 2010 in Hegyhatsal over grassland

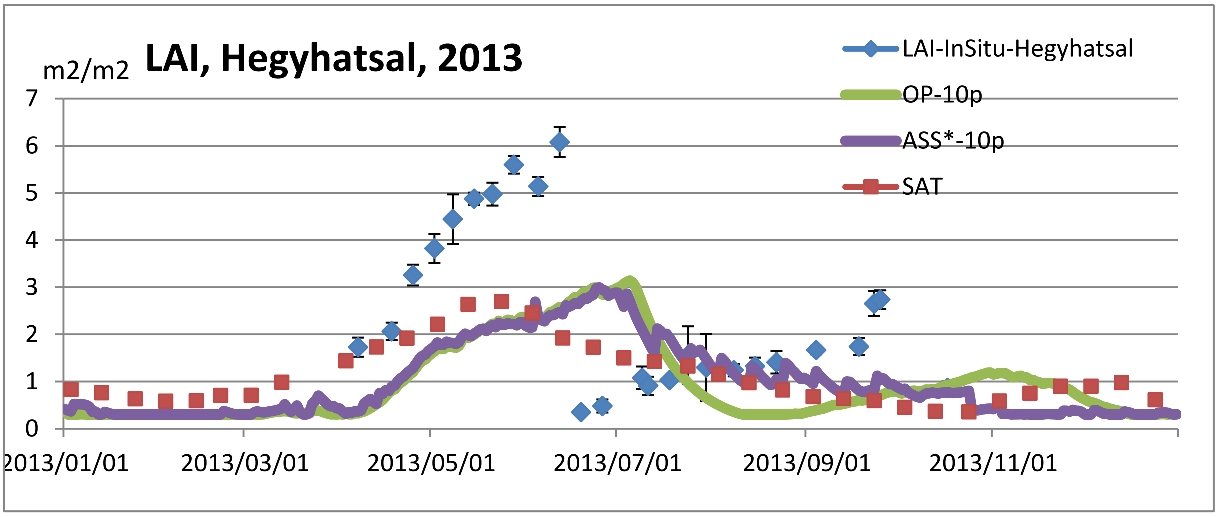


Figure 3: LAI in 2013 in Hegyhatsal over grassland

2.2.2 Root-zone Soil Moisture

Soil moisture is measured with Campbell CS615, from 10-40 cm in the soil and the daily means are calculated from the 8 minutes measurements. The observed soil moisture content is about 1.5 times more than the simulated values (Figure 4 and Figure 5). Small differences can be seen between the two simulations (open-loop and assimilation), but the assimilation run (purple line) gives better representation of the very dry summer period in 2013 (Figure 5).

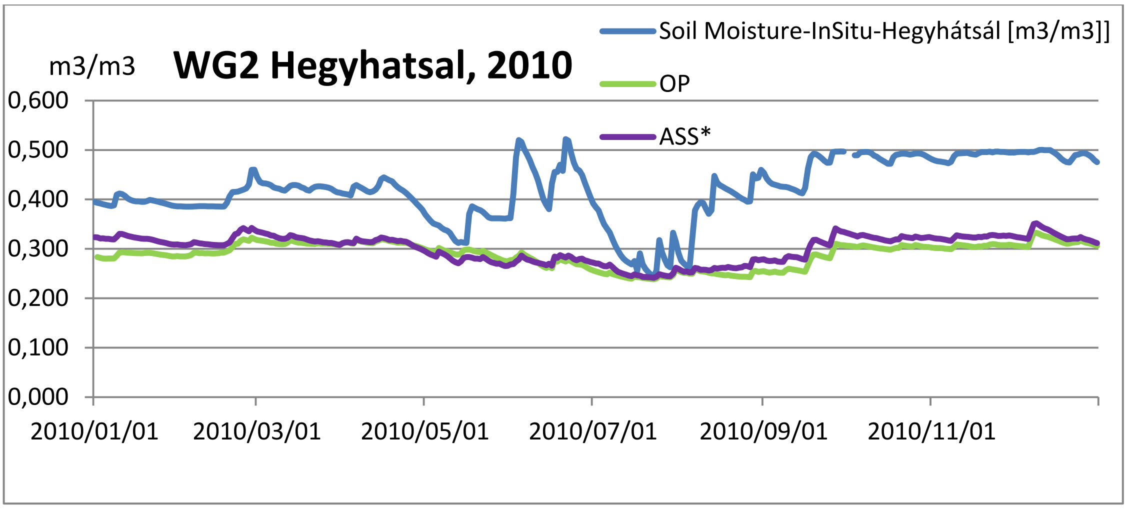


Figure 4: Root zone soil moisture (WG2) in 2010

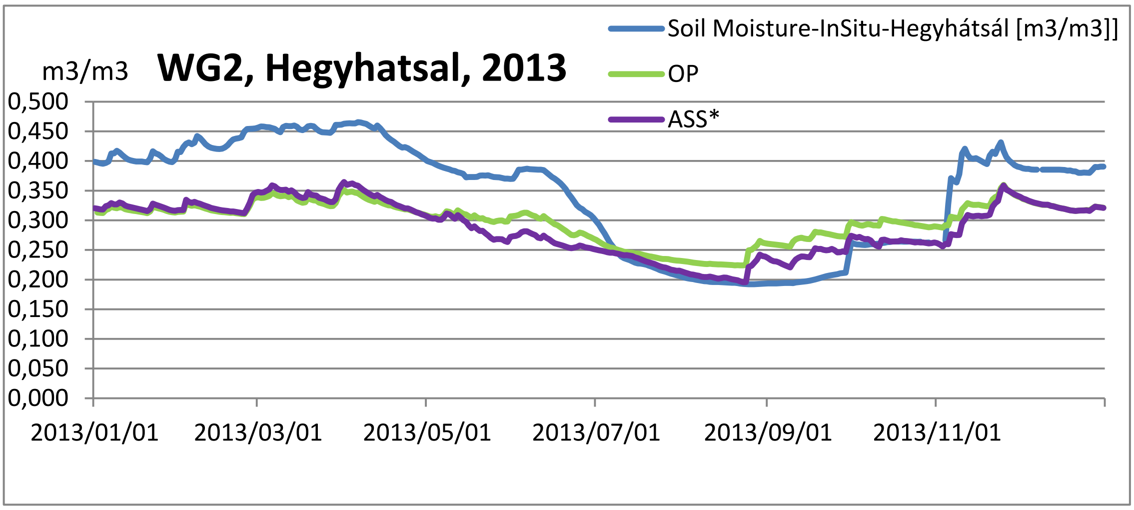


Figure 5: Root zone soil moisture (WG2) in 2013

2.2.3 Gross Primary Production (GPP), Net Ecosystem Exchange (NEE) at 3 m and 82 m

Daily averaged NEE is a measured, while GPP is a derived parameter. By contrast in the surface model, GPP is calculated exactly, the NEE should be recalculated. As it is known:

$$NEE = Reco - GPP \tag{1}$$

where Reco is the ecosystem respiration. The calculation of Reco in ISBA-A-gs depends, in particular, on the soil temperature and the soil moisture. The yearly sum of NEE should be 0 because the net of CO_2 flux is about 0 for the whole year:

$$sumNEE = sumReco - sumGPP = 0 \quad (2)$$

Reco is re-calculated in the following way:

$$Reco' = Reco * \frac{sumGPP}{sumReco} \quad (3)$$

From the recalculated Reco', the NEE' could be defined:

$$NEE' = Reco' - GPP \quad (4)$$

NEE' is well simulated almost the whole year 2013 for both experiments (open-loop and assimilation) for both heights (3 m and 82 m), except for the summer and autumn, when the experiments give positive NEE' values – this means emission of CO_2, but the measurements are negative – which means uptake of CO_2 (Figure 6 and Figure 7).

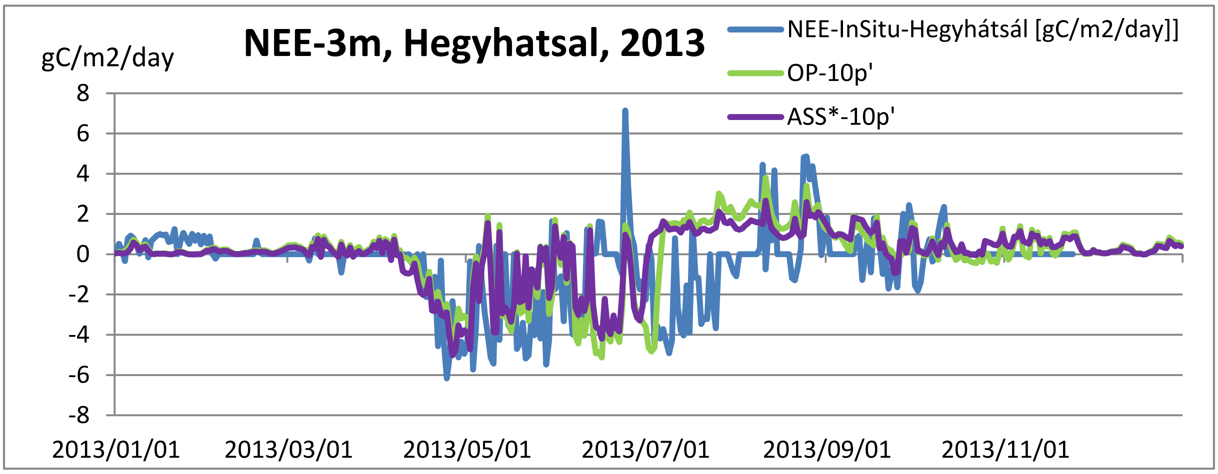


Figure 6: NEE at 3 m in 2013

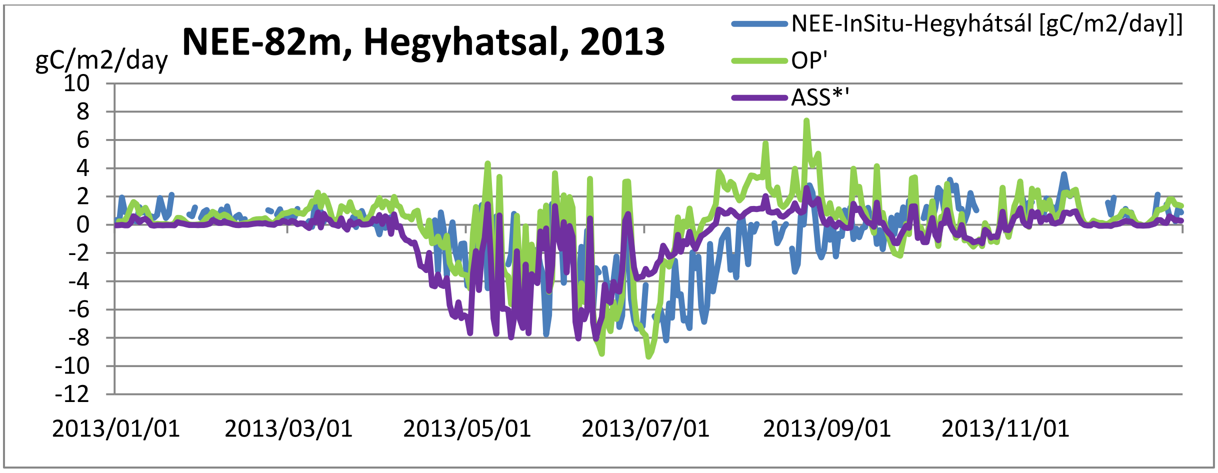


Figure 7: NEE at 82 m in 2013.

2.2.4 1D Statistics

Some standard statistics (bias and RMSE) are shown in Figure 8 for the period 2008-2013 compared to the in-situ measurements. Small differences can be found between the results calculated from two kinds of simulations, but it is well seen that the RMSE of the assimilation is smaller than the RMSE of the open-loop run for NEE at 82 m height. NEE is underestimated compared to in-situ measurements by the assimilation run for the whole period, while LE is overestimated for period of 2008-2010 and underestimated for the period of 2011-2013 for both heights

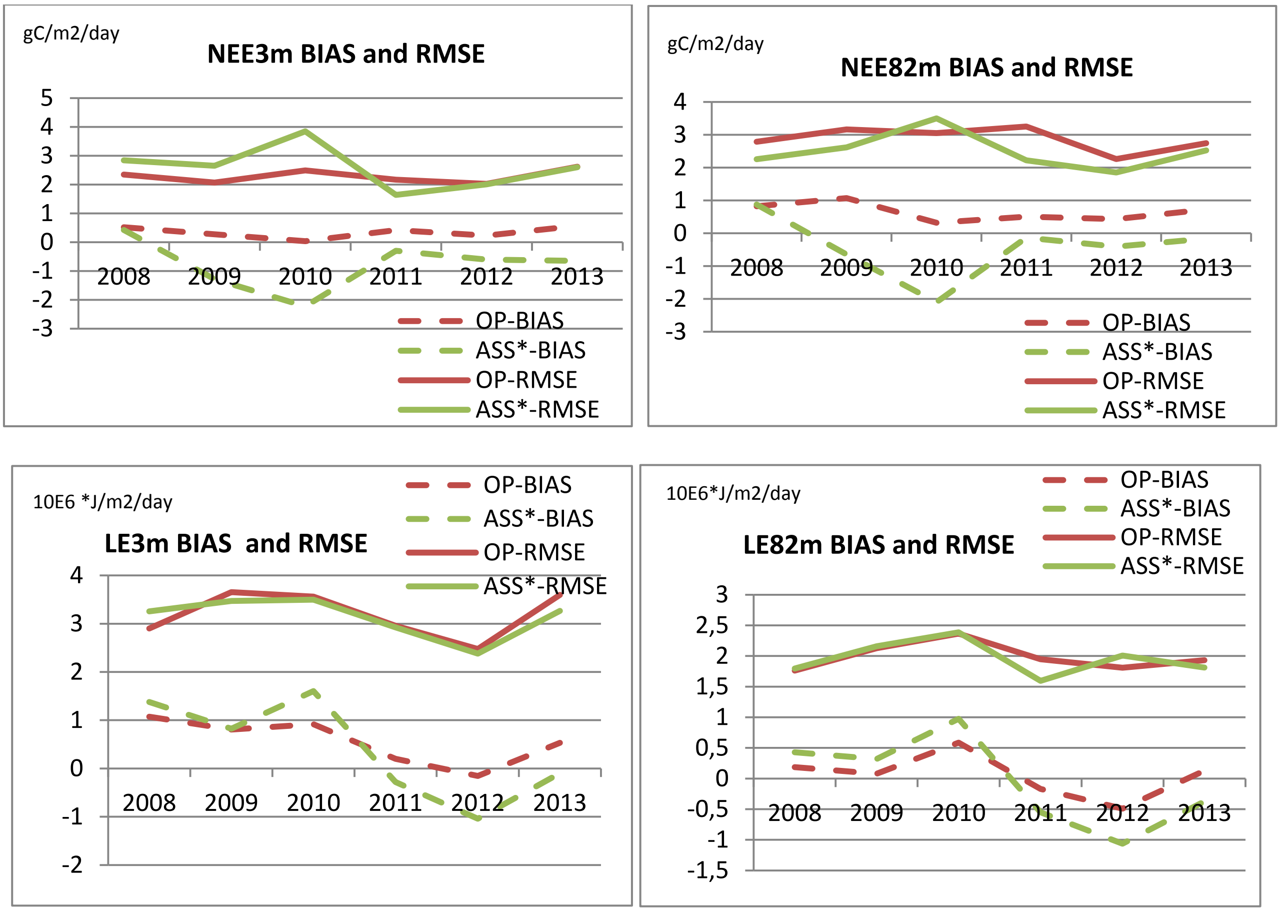


Figure 8: Statistics (Bias: dashed lines; RMSE: full lines) of NEE and LE for the both experiments (open-loop in red, assimilation in green)

2.3 2D VALIDATION

2.3.1 Inter-annual variability of LAI and WG2

The ability of the modeling system to simulate inter-annual variability has also been validated in 2D over Hungary. Six years (2008-2013) have been simulated using SPOT/VGT GEOV1 LAI assimilation and open-loop runs. These six years were used as a baseline to calculate monthly anomalies for the year 2012, when an extremely strong drought affected Hungary. The normalized anomaly was calculated as

$$AnoX = \frac{X - < X >}{stdev(X)}$$

where <*X*> stand for the long year monthly average and *stdev(X)* indicates the standard deviation. *X* can be variables such as LAI or root-zone soil moisture (WG2). *AnoX* could be calculated for either monthly or 10-day periods for the simulations and also for the satellite data. When root-zone soil moisture is examined, SWI-10 is used from the satellite, which is an average of SWI over a 10 days period and well correlates with WG2. Figure 9 shows the monthly *AnoLAI* values calculated from satellite products and from the simulations (open-loop and assimilations). Both models are able to reproduce the extremely low LAI anomalies in 2012 but the root-zone soil moisture anomalies (Figure 10) are better represented in the assimilation run at late summer and autumn of year 2012. The negative anomaly is appearing in the soil moisture measurements of Hegyhatsal in 2012 (Figure 11).

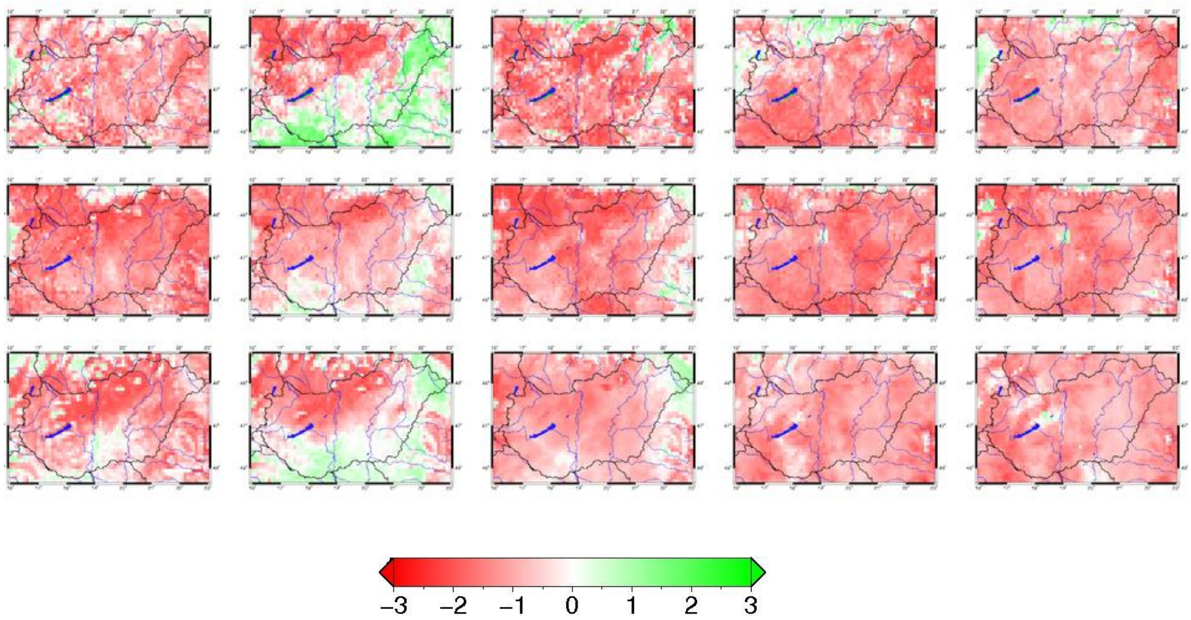


Figure 9: Monthly anomalies for the year 2012 from May to October: SPOT/VGT GEOV1 LAI product (first row), assimilated LAI (second row) and open-loop LAI (third row)

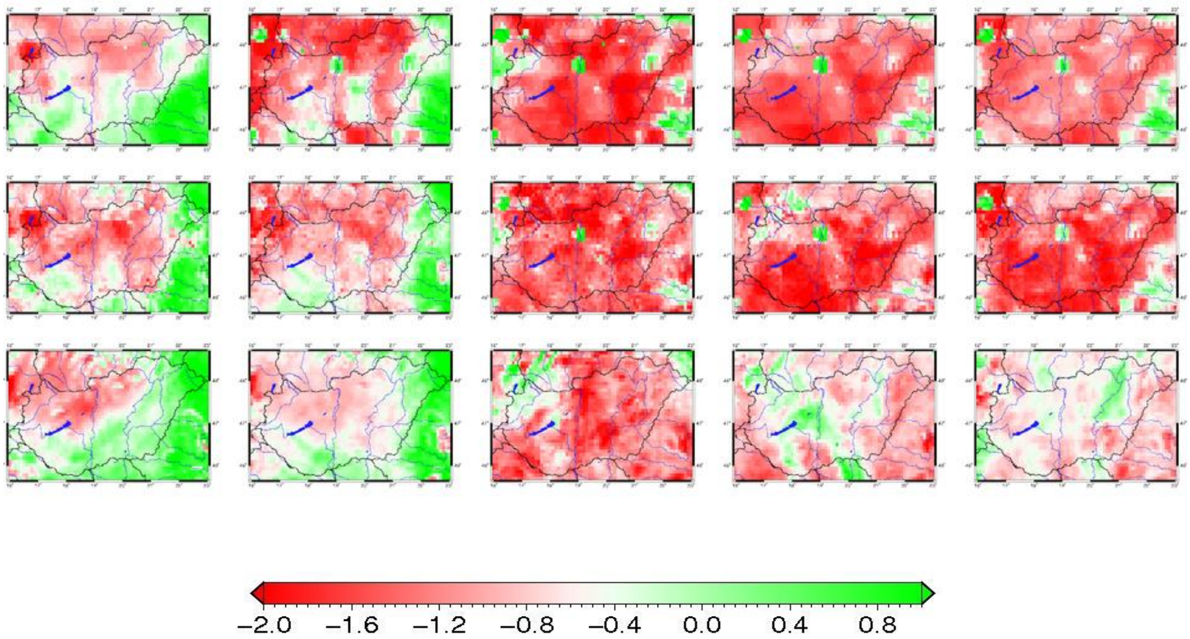


Figure 10: Monthly anomalies for the year 2012 from May to October: ASCAT/SWI-10 product (first row) assimilated WG2 (second row) and open-loop WG2 (third row)

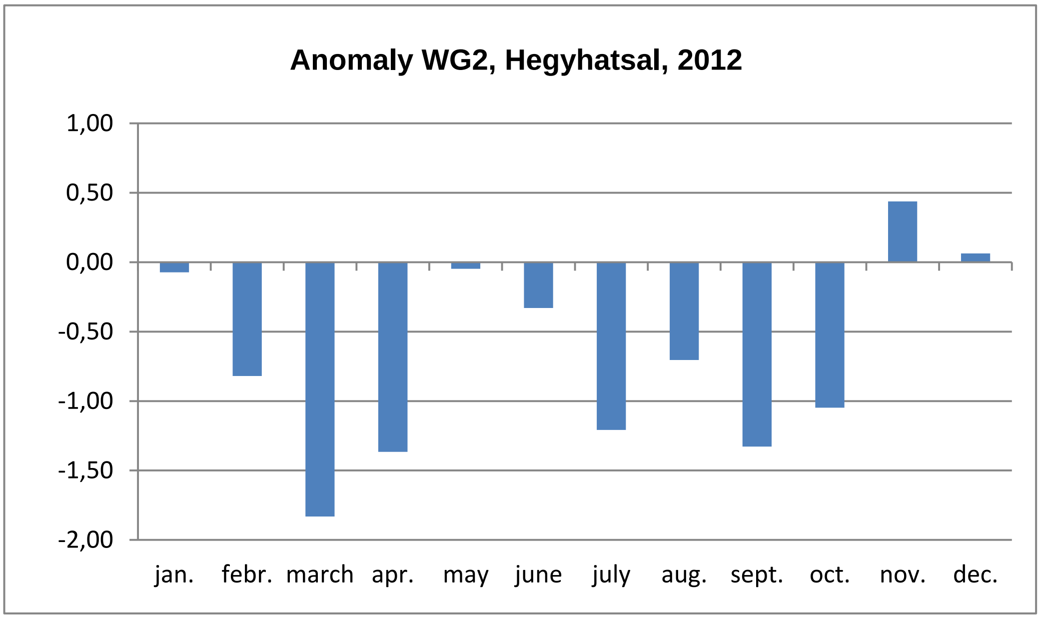
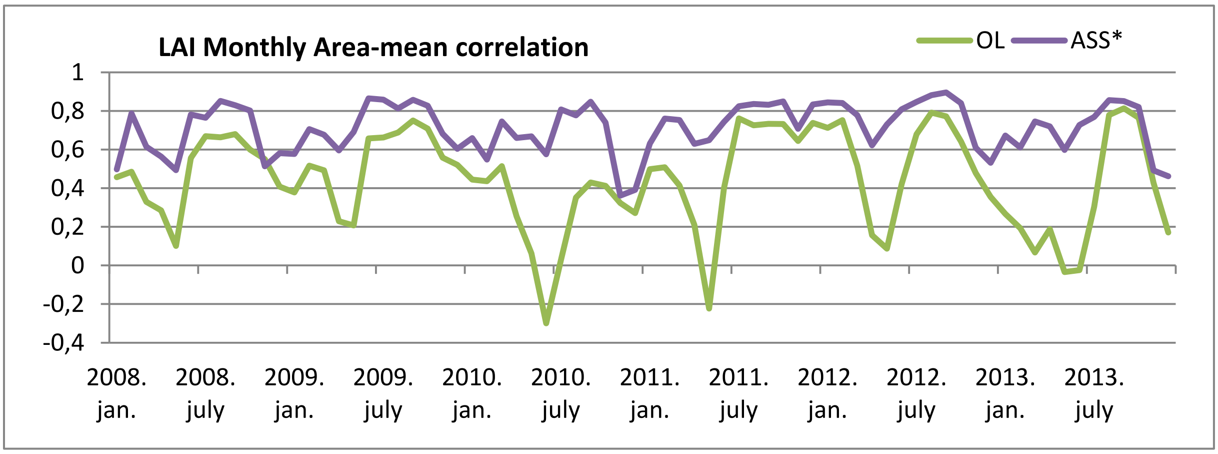


Figure 11: Monthly soil moisture anomalies measured at Hegyhatsal for year 2012

2.3.2 2D Statistics for LAI and SWI

Standard statistics such as correlation, bias and RMSE are calculated against the satellite information for both kinds of simulations. Monthly area-mean LAI and SWI scores are illustrated in Figure 12 and Figure 13. SWI values are computed from the simulations using of WG2 (root-zone water content): $SWI=(WG2-WG2_{min})/(WG2_{max}-WG2_{min})$, where $WG2_{min}$ and $WG2_{max}$ are come from the model run. To calculate the scores for SWI we used the ASCAT SWI-10 satellite data.



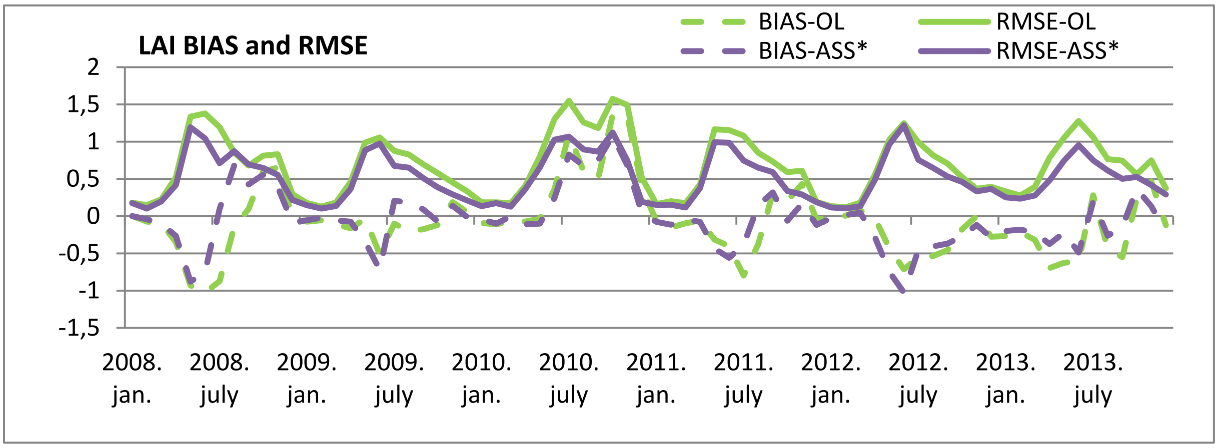
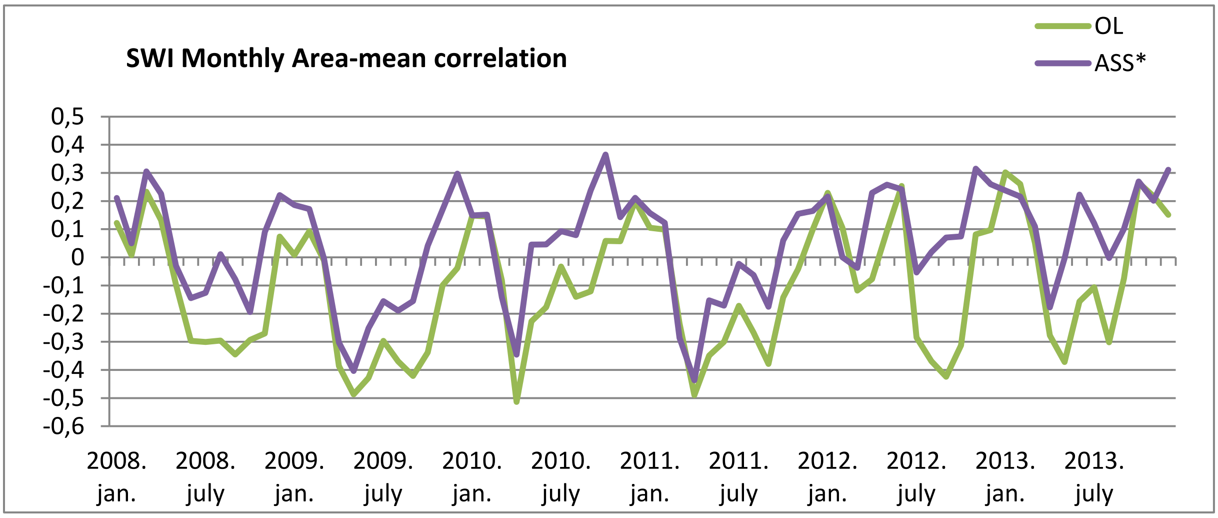


Figure 12: 2D statistics (top: mean correlation; bottom: bias (dashed line) and RMSE (full line)) for LAI for open-loop (green) and assimilation (purple) runs.

The open-loop experiment produces low correlation for LAI at every spring time repeatedly, especially in May, and these weak correlations disappear in the summer or autumn period. In the assimilation, these wrong correlations do not appear, the extended Kalman filter (EKF) works properly (Figure 12, top). LAI is underestimated by the models (negative bias) especially for the summer months, except for 2010, when the amount of biomass was overestimated for the whole year (Figure 12, bottom). In Figure 13, the assimilation run shows slightly better correlations than the open-loop run for SWI, but low correlations exist in spring periods. BIAS and RMSE are similar for both simulations.



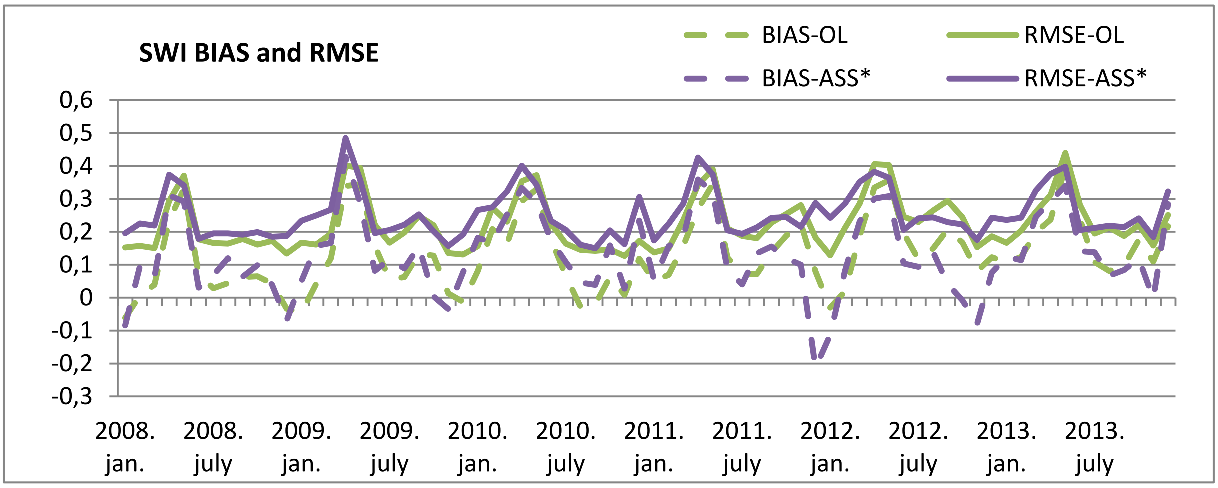


Figure 13: 2D statistics (top: mean correlation; bottom: bias (dashed line) and RMSE (full line)) for SWI for open-loop (green) and assimilation (purple) runs.

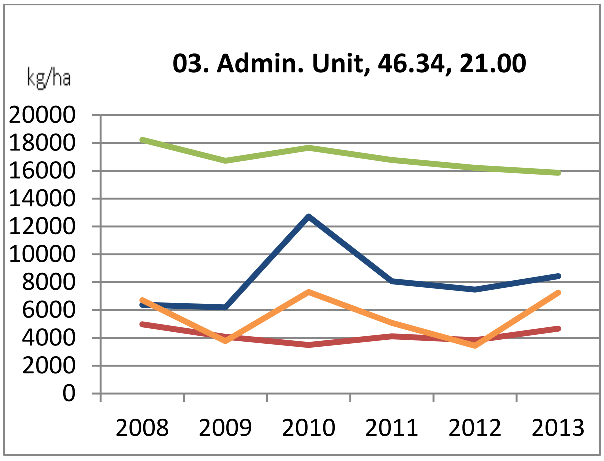
2.4 AGRICULTURE

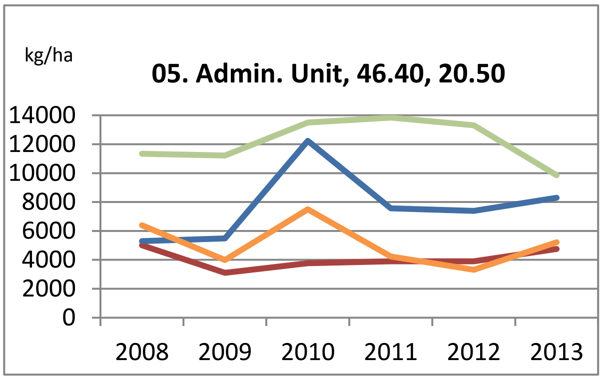
Biomass is a prognostic variable and is directly affected by the LDAS systems and used for agricultural validation. Agricultural observations such as straw cereal yield measurements are used for this validation over Hungary. A comparison with crop model-based results is also performed. The validation is done for the 9 straw cereal locations in Hungary.

WOFOST is a crop growth model that allows the estimation of yields quantitatively, developed by the Department of Theoretical Production Ecology (Wageningen Agricultural University, The Netherlands) and the Center for Agrobiological Research and Soil Fertility (Wageningen, The Netherlands). This model is implemented currently within the MARS Crop Growth Monitoring System (CGMS), allowing the estimation of biophysical variables related with crop yields such as potential biomass production, crop development stage, etc).

WOFOST raw simulations were provided by JRC. They are done at soil unit level and multiple times for each of the soil types within a soil polygon. Then they are aggregated according to the provided information about the coverage of the soil types within the soil unit polygon intersected by the grid of 25 by 25 km. The WOFOST grid points corresponding to 9 straw cereal locations in Hungary were used for this validation. Data for soft wheat were extracted from 2008 to 2013 in 10 daily steps for water limited above-ground biomass (kg/ha).

The WOFOST data were compared with the ISBA-A-gs outputs for straw cereals before (open loop) and after data assimilation, as well as with the in situ yield data provided by the Centre Office for Statistics in Hungary (KSH). Results are illustrated in Figure 14 for all sites in Hungary defined in the Product User Manual. The most accurate biomass estimate is given by the assimilation run compared to the in-situ yield. WOFOST and the open-loop runs overestimate the wheat biomass production for all sites. The scatter-plot (Figure 15) shows the summarized information coming from the estimations. The assimilated above-ground biomass correlates with the in-situ yield: R = 0.25 (without the outlier data from 2010, R = 0.56), while the open-loop simulation is uncorrelated with in-situ R = -0.13 (without 2010, R = 0.28), WOFOST estimation has also a poor correlation: R = 0.15 (without 2010, R = 0.32). Figure 16 shows the relative anomaly maps calculated from the model biomass production and the observed yield statistics for all counties in Hungary for the wet year 2010 and for the drought year 2012. More accurate yield simulation can be performed if the assimilation of the satellite observations is used.


03. Admin. Unit, 46.34, 21.00
kg/ha
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
2008 2009 2010 2011 2012 2013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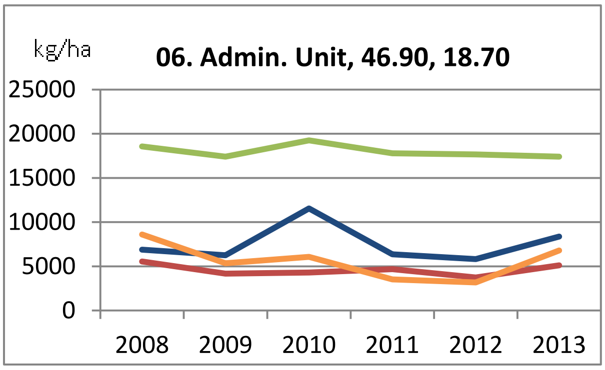
kg/ha
14000
12000
10000
8000
6000
4000
2000
0
2008 2009 2010 2011 2012 2013


06. Admin. Unit, 46.90, 18.70
kg/ha
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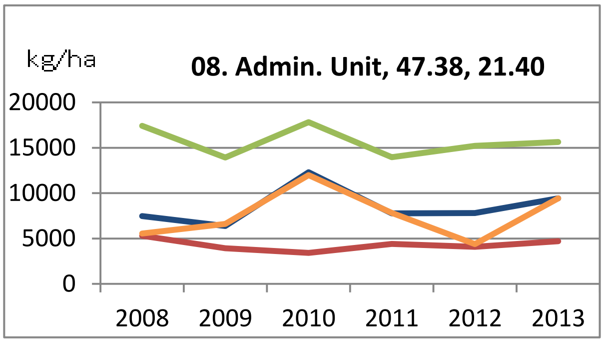
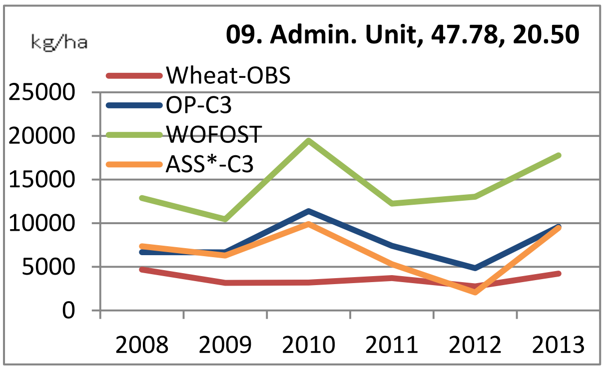
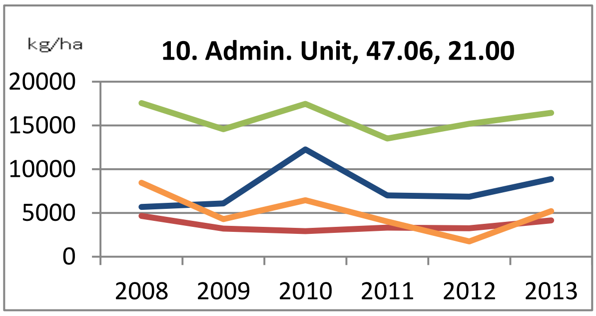
20000
15000
10000
5000
0
2008 2009 2010 2011 2012 2013


08. Admin. Unit, 47.38, 21.40
kg/ha
20000
15000
10000
5000
0
2008 2009 2010 2011 2012 2013


09. Admin. Unit, 47.78, 20.50
kg/ha
Wheat-OBS
OP-C3
WOFOST
ASS*-C3
25000
20000
15000
10000
5000
0
2008 2009 2010 2011 2012 2013


10. Admin. Unit, 47.06, 21.00
kg/ha
20000
15000
10000
5000
0
2008 2009 2010 2011 2012 2013

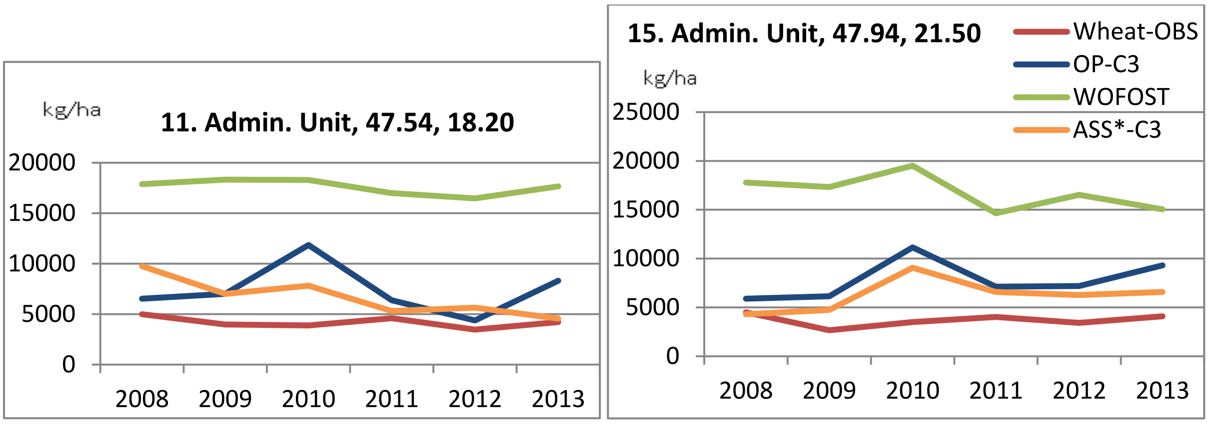


Figure 14: Wheat type biomass production estimate with (orange line) and without (blue line) assimilation vs. observed yield (red line) vs. WOFOST estimate (green line) for the selected administrative units

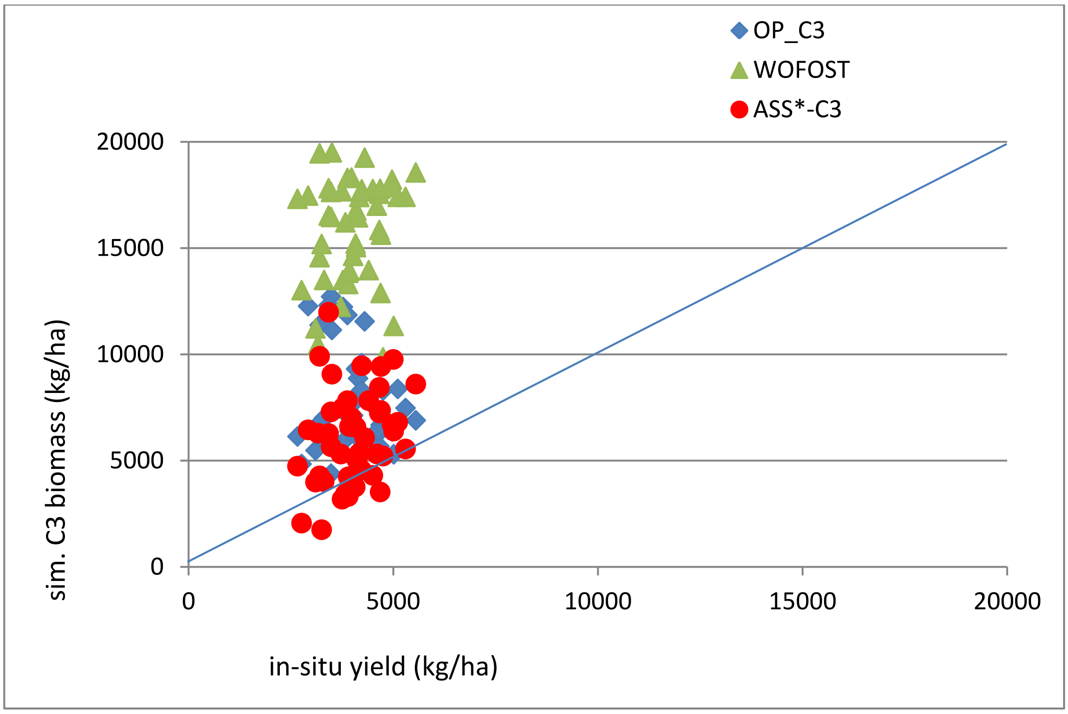


Figure 15: Scatter plot: Simulated above-ground biomass of straw cereals (open-loop (blue diamond), assimilation (red circles) and WOFOST estimation (green triangles)) vs. observed yield, over 8 administrative units in Hungary for the period of 2008-2013

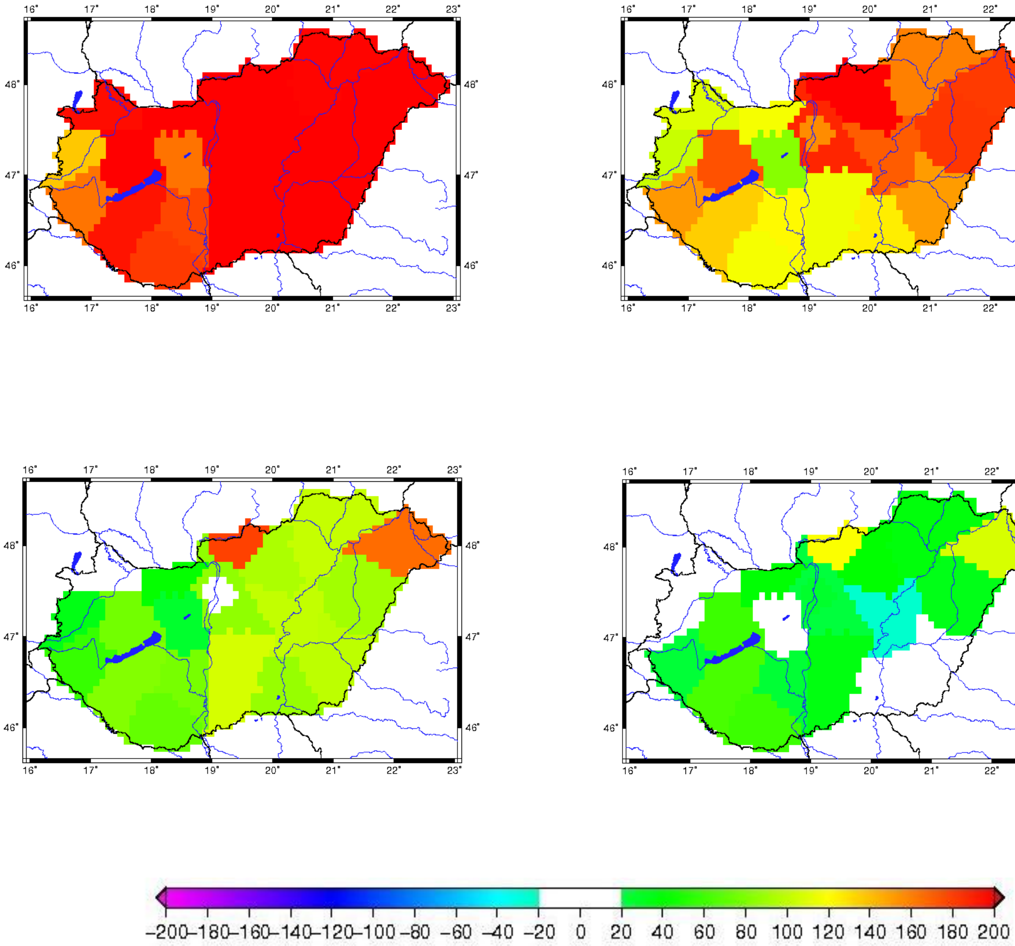


Figure 16: Relative anomaly maps for Hungary in 2010 (first row) and in 2012 (second row), on the left: open-loop, on the right: assimilation

3 CONCLUSIONS AND PROSPECTS

In the framework of the IMAGINES project a Land Data Assimilation System was applied at the Hungarian Meteorological Service to monitor the above ground biomass, surface fluxes (carbon and water) and the associated root-zone soil moisture at the regional scale (spatial resolution of 8km x 8km) in quasi real time. In this system, the SURFEX 7.3 model was used, which applies the ISBA-A-gs photosynthesis scheme to describe the evolution of vegetation. SURFEX was forced using the outputs of the ALADIN numerical weather prediction model run operationally at OMSZ. First, SURFEX was run in open-loop (i.e. no assimilation) mode for period 2008-2013. Secondly, the Extend Kalman Filter (EKF) method was used to assimilate SPOT/VGT LAI and SWI ASCAT/Metop satellite measurements. The EKF run (with assimilation) was compared to the open-loop simulation and to observations (LAI and Soil Moisture satellite products) over the whole country and also to a selected site in West-Hungary (Hegyhatsal).

It has been shown that the above-ground biomass simulated by ISBA-A-gs over wheat relates very well to agricultural yields if the assimilation of both satellite observations (LAI and SWI) is performed.

In the framework of ImagineS projects the following developments are planned in the near future: 1) using of new satellite product in LDAS chain (higher resolution GEOV3 LAI from PROBA-V), 2) new kind of satellite data will be assimilated (as FAPAR, surface albedo), 3) demonstrate our promising products as crop estimations and drought indicators to the potential end-users (experts from Ministry of Agriculture and Agricultural Directorate).

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