IMPLEMENTING MULTI-SCALE AGRICULTURAL INDICATORS EXPLOITING SENTINELS

PRODUCT USER MANUAL

LAND DATA ASSIMILATION SYSTEM PRODUCTS

IMAGINES_RP6.3_PUM-LDAS

ISSUE I1.20

EC Proposal Reference N° FP7-311766

Due date of deliverable: June 2015

Actual submission date: 16.07.2015

Start date of project: 01.11.2012 Duration : 40 months

Name of lead partner for this deliverable: Meteo-France

Book Captain: Jean-Christophe Calvet (Meteo-France)

Contributing Authors: Gianpaolo Balsamo, Souhail Boussetta (ECMWF), Helga Toth (OMSZ)

Project co-funded by the European Commission within the Seventh Framework Program (2007-2013)		
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:	Jean-Christophe Calvet	Date: 20.05.2016	Sign. 
Approval:	R. Lacaze	Date: 23.05.2016	Sign. 
Endorsement:	M. Koleva	Date:	Sign.
Distribution:	Public		

CHANGE RECORD

Issue/Revision	Date	Page(s)	Description of Change	Release
	16.07.2015	All	Initial issue	I1.00
I1.00	15.01.2016	16	Add details in Table 1	I1.10
I1.10	20.05.2016	46-51	Revision of Hungarian LDAS figures in ANNEX 3 and 4	I1.20

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS

AGB	Above-Ground Biomass
ALADIN	Aire Limitée Adaptation Dynamique Developpement InterNational
ASCAT	Advanced Scatterometer
ATBD	Algorithm Theoretical Basis Document
CTESSEL	Carbon-Tiled EE
DI	Drought Indicator
ECMWF	European Centre for Medium-range Weather Forecast
EKF	Extended Kalman Filter
EU	European Union
FAPAR	Fraction of Absorbed Photosynthetically Active Radiation
FLUXNET	FLUX tower NETwork
GEOGLAM	Global Agricultural Geo-Monitoring Initiative
GEO	Group on Earth Observations
GEOVx	Family of vegetation products (LAI, FAPAR, FCover, surface albedo) of version x provided by the Copernicus Global Land service
GPP	Gross Primary Production
GRIB	General Regularly-distributed Information in Binary form/or GRIdded Binary
HIRLAM	High Resolution Limited Area Model
IFS	Integrated Forecasting System
ISBA	Interactions between Soil Biosphere Atmosphere
LAI	Leaf Area Index
LDAS	Land Data Assimilation System
MARS	ECMWF Meteorological Archiving and Retrieval System
NEE	Net Ecosystem CO_2 Exchange
NetCDF	Network Common Data Form
PROBA-V	VEGETATION sensor on Project for OnBoard Autonomy platform
PUM	Product User Manual
Reco	Ecosystem Respiration
SAFRAN	Système d'Analyse Fournissant des Renseignements Atmosphériques à la Neige
SURFEX	Externalized surface
VGT	VEGETATION sensor onboard SPOT satellites
SWI	Soil Wetness Index
WOFOST	WOrld FOod STudies

1. BACKGROUND OF THE DOCUMENT

1.1. EXECUTIVE SUMMARY

The Copernicus program is the EU response to the increasing demand for reliable environmental data. The objective of the Copernicus Land Service is to continuously monitor and forecast the status of land territories and to supply reliable geo-information to decision makers, businesses and citizens to define environmental policies and take right actions. ImagineS intends to continue the innovation and development activities to support the operations of the Copernicus Global Land service, preparing the use of the new Earth Observation data, including Sentinels missions data, in an operational context. Moreover, ImagineS aims to favor the emergence of downstream activities dedicated to the monitoring of crop and fodder production, that are key for the implementation of the EU Common Agricultural Policy, of the food security policy, and could contribute to the Global Agricultural Geo-Monitoring Initiative (GEOGLAM) coordinated by the intergovernmental Group on Earth Observations (GEO).

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) 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) in order 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.

ImagineS considers two LDAS platforms:

1. The first one has a global coverage and is based on the ECMWF CTESSEL Land Surface Model (LSM) (Balsamo et al. 2009, Balsamo et al. 2011, Boussetta et al. 2013a, Boussetta et al. 2013b). The CTESSEL model is implemented in the Integrated Forecast System (IFS) and is operational at ECMWF. This implies that the entire suites of forecasting products can output Net Ecosystem Exchange of CO2 (NEE), Gross Primary Production (GPP) and Ecosystem Respiration (Reco). For the purpose of the ImagineS project, CTESSEL was upgraded in research mode to consider interactive vegetation and biomass output.

2. The second one is a LDAS developed in the SURFEX modeling platform, which includes the ability of performing regional experiments. It 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. 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 France and Hungary at a spatial resolution of 8 km.

This document describes the global and regional LDAS output.

1.2. SCOPE AND OBJECTIVES

The PUM is a self-contained document which gathers all necessary information to use the product on an efficient and reliable way. It gives an overview of the products properties, in terms of algorithm, technical characteristics and main validation results.

1.3. CONTENT OF THE DOCUMENT

The document is structured as follows:

- Chapter 2 focuses on Global LDAS products.
- Chapter 3 describes the regional LDAS products.
- Chapter 4 presents the quality assessment of the products.

1.4. RELATED DOCUMENTS

Document ID	Descriptor
IMAGINES_RP1.2_SSD	Service Specifications Document
IMAGINES_RP2.1_ATBD_LDAS	Algorithmic Theoretical Basis Document of the LDAS products
IMAGINES_RP7.2_SVP	Service Validation Plan
IMAGINES_RP7.4_VR_LDAS-Global	Validation report of the global LDAS products
IMAGINES_RP7.4_VR_LDAS-France	Validation report of regional LDAS-France products
IMAGINES_RP7.4_VR_LDAS-Hungary	Validation report of regional LDAS-Hungary products

2. ECMWF GLOBAL LDAS

Within the Copernicus Global Land service, coordinated efforts are made to produce biophysical variables that describe the continental vegetation state, radiation budget and water cycle with the objective of developing and validating operationally oriented land information services. In particular, satellite-derived products of soil moisture (Soil Water Index), Leaf Area Index (LAI) and albedo are being produced. Including this new information in a Global Land Data Assimilation System (LDAS) and assessing its impact contributes to a better characterization of the vegetation state, permits the monitoring of the surface fluxes (carbon and water) and the associated root-zone soil moisture at the global scale.

The global LDAS is developed within the ECMWF system up to pre-operational phase. The CTESSEL model is operationally implemented in the Integrated Forecast System (IFS). This implies that the entire suites of forecasting products can output Net Ecosystem Exchange of CO_2 (NEE), Gross Primary Production (GPP) and Ecosystem Respiration (Reco). Apart from this online real-time production chain, an offline LDAS chain is able to assimilate satellite-derived LAI and albedo products and can be attached to the ECMWF reanalysis depending on favourable assessment. The ImagineS products benefit from the coupling of this offline chain with the near real time chain.

At the moment, four different analysis schemes are active for the surface (and near-surface) variables based, respectively, on spatial Optimum Interpolation (2D-OI, used snow depth and screen-level analyses), the column Optimum Interpolation (1D-OI, used for soil/snow temperature analysis), a Simplified EKF (SEKF, used for soil moisture analysis) and the assimilation of the Leaf Area Index (LAI) and albedo is based on a simple 1D optimal interpolation method (Gu et al., 2006 and Boussetta et al., 2015a) which is well adapted to the current global system. All schemes operate independently from the atmospheric analysis.

2.1. THE GLOBAL LDAS CHARACTERISTICS

Table 1 summarizes the characteristics of the global LDAS. More details can be found in the Algorithm Theoretical Basis Document [IMAGINES_RP2.1_ATBD_LDAS]

Table 1: Summary of ECMWF global LDAS characteristics

Inputs	Screen-level parameters*, ASCAT-Soil moisture*, GEOVx LAI, GEOVx albedo
Outputs	Analyzed LAI, analyzed albedo, Root-zone soil moisture, NEE, GPP, Evapo-transpiration
Interfaces	ECMWF IFS (European Centre for Medium-range Weather Forecasts - Integrated Forecasting System)
Capacity requirements	CRAY XC30 Supercomputing facility, MARS storage system

* input to the ECMWF operational LDAS system, not considered in the ImagineS project

2.2. THE GLOBAL PRODUCTS

A set of global products is generated in the framework of ImagineS and archived under the ECMWF Meteorological Archiving and Retrieval System (MARS).

2.2.1. Variables

The global LDAS products contain the following variables and indicators:

Leaf Area Index (LAI):

The LAI expresses the state of development of the active layers of the plants (the leaves) and has units of m^2 (of leaves) per m^2 (of soil). The LAI typically ranges between 0 and 7. In CTESSEL, it is varying from day-to-day. The LAI is assimilated within CTESSEL based on the work of Gu et al. (2006) and Boussetta et al (2015a). It is also provided as disaggregated quantities for low and high vegetation types.

Net Ecosystem Exchange (NEE):

The NEE is the net natural CO_2 flux exchanged between the biosphere and the atmosphere as simulated by the CTESSEL model and constrained by the LDAS system. This value is useful in atmospheric simulations of CO_2 concentration as it permits to simulate natural sources and sink of CO_2 that together with ocean emission and anthropogenic emissions characterize the day-to-day variability in CO_2.

Gross Primary Production (GPP):

This quantity represents the CO_2 fixed by the vegetation via the photosynthetic activity of the land biospheric component.

Drought indicator (DI):

The drought indicator is a scaled anomaly index of a parameter V_i for a particular day or 10-day period i with regard to its standard deviation σ_{V_i} over the 1999-2013 period. It follows Szczypta et al. (2014) and is expressed as

$$DI_V = \frac{V_i - \overline{V}_{i,1999\text{–}2013}}{\sigma_{V_i}},$$

where $\overline{V}_{i,1999\text{–}2013}$ is the average value for day/10-day i over the 1999-2013 period. In this case we compute the drought indicator based on LAI, root zone soil moisture, NEE and above-ground biomass (AGB).

Anomaly index (AI):

The anomaly index can be also considered as drought indicator and is expressed as the anomaly of a parameter V_i for a particular day or 10-day period i with regard to its 1999-2013 average $\overline{V}_{i,1999\text{–}2013}$ for the same period i. It is formulated as:

$$AI_V = \frac{V_i - \overline{V}_{i,1999\text{–}2013}}{\overline{V}_{i,1999\text{–}2013}} * 100$$

In this case, we compute the Anomaly Index based on LAI, root zone soil moisture, NEE and AGB (Figure 1).

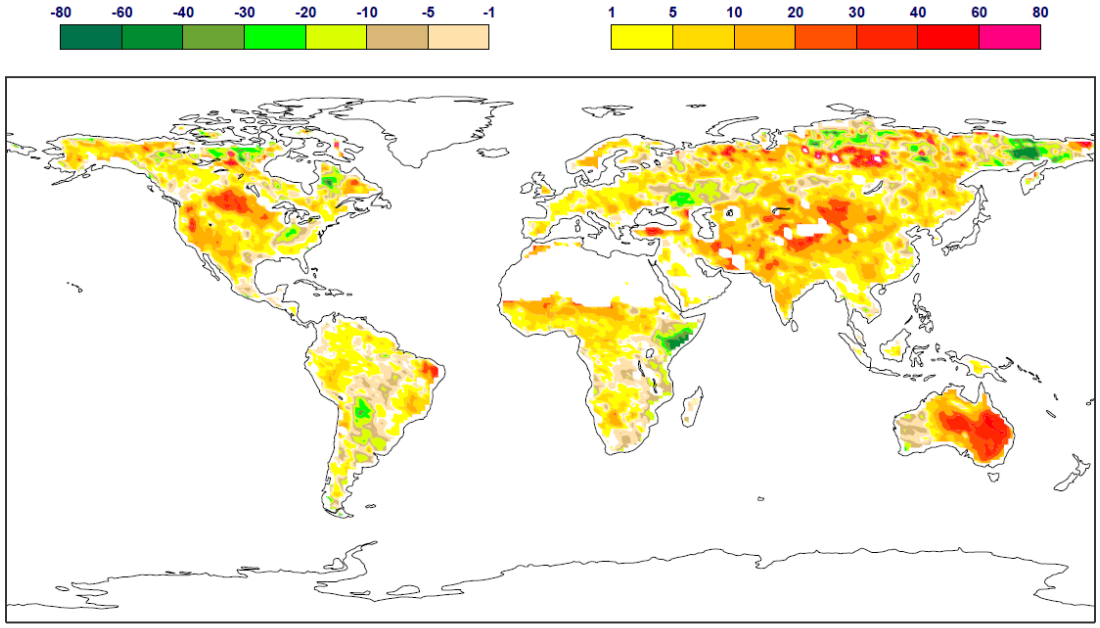

Figure 1: Above ground biomass-based Anomaly Index (AI_{AGB}) for November 2010 in [%] of the 1999-2013 mean.

2.2.2. File Format

The global MARS archived products are available in GRIB and NetCDF formats.

2.2.3. Product Characteristics

The global LDAS products are provided in Gaussian reduced projection at the spatial resolution of 16km. Other properties are presented in Table 2. Note that “GRIB paramId” is the number used to identify its corresponding parameter within the GRIB file.

Table 2: ECMWF global LDAS products characteristics

Name	Temporal resolution	GRIB paramId	Units
Net Ecosystem Exchange	3-hourly	228080	kg CO_2 m^{-2} d^{-1}
Gross primary production	3-hourly	228081	kg CO_2 m^{-2} d^{-1}
Evapotranspiration	3-hourly	182.128	kg H_2O m^{-2} d^{-1}
Above ground Biomass	3-hourly	210064	$kg.m^{-2}$
Volumetric soil moisture layer (0-7 cm)	6-hourly	39.128	$m^3.m^{-3}$
Volumetric soil moisture layer (7-28cm)	6-hourly	40.128	$m^3.m^{-3}$
Volumetric soil moisture layer (28-100cm)	6-hourly	41.128	$m^3.m^{-3}$
Leaf Area Index	Daily	129066	$m^2.m^{-2}$
LAI based drought indicator	Daily	81.128	-
LAI based anomaly index	Daily	82.128	-
NEE based drought indicator	Daily	85.128	-
NEE based anomaly index	Daily	86.128	-
AGB based drought indicator	Daily	91.128	-
AGB based anomaly index	Daily	92.128	-
Root zone soil moisture based drought indicator	Daily	101.128	-
Root zone soil moisture based anomaly index	Daily	102.128	-

2.3. THE LOCAL SIMULATIONS

For easiness of interpretation and accessibility, a set of local simulations is provided over 85 sites scattered around the globe for crops and grassland. They represent their corresponding 16km grid from the global simulation.

This selection has demonstrational purposes and permits the activities of Quality Control and Quality Assessment attached to the LDAS.

2.3.1. Folder and files contents

The global LDAS local simulations are provided in a tarred file that shall be un-tarred using the following option:

```
tar –xvzf ImagineS_Global_LDAS.tar.gz
```

Note that Windows-based un-tarring software may lead to overwriting files due to shortening file-name.

The global LDAS local simulations are provided in daily and 10-daily time series. The files are organized in 2 folders named, respectively, “daily” and “decade”. Each contains 85 subfolders of the 85 sites. The subfolders are named according to the site naming convention used in Table 4.

Each site subfolder contains 3 types of products for the considered 7 parameters (i.e. 21 files):

The considered parameters are:

- Leaf Area Index (LAI) in [m2 m^{-2}]
- Root zone Soil moisture (SM) in [m3 m^{-3}]
- Surface soil moisture (SSM) in [m3 m^{-3}]
- Evapotranspiration (ETR) in [kg H2O m^{-2} day^{-1}]
- Net ecosystem exchange (NEE) in [kg CO2 m^{-2} day^{-1}]
- Gross primary productivity (GPP) in [kg CO2 m^{-2} day^{-1}]
- Above-ground biomass (AGB) [kg m^{-2}]

The product types are:

- Time series of mean daily/10-daily parameters
- Drought indicator
- Anomaly index

The files are named according to the following convention:

LDAS_Global_<SiteName>_<ProductType>_<Frequency>_<Acronym>.csv

Where

- SiteName is the name of each 85 sites as listed in Table 4
- ProductType stands for “TimeSeries”, “DroughtIndicator” or “AnomalyIndex”
- Frequency is “daily” or “decade”
- Acronym refers to the variables as listed in Table 3.

Table 3: Acronyms and units of variables provided in the local simulations of Global LDAS products

Product name	Abreviation	Units
Leaf Area Index	LAI	$m^2\ m^{-2}$
Root-zone soil moisture	SM	$m^3\ m^{-3}$
Surface soil moisture	SSM	$m^3\ m^{-3}$
Evapotranspiration	ETR	$kgH_2O\ m^{-2}\ d^{-1}$
Net Ecosystem Exchange	NEE	$kgCO_2\ m^{-2}\ d^{-1}$
Gross primary production	GPP	$kgCO_2\ m^{-2}\ d^{-1}$
Above ground biomass anomaly	AGB	%

2.3.2. File format

The 21 files of each site subfolders are provided in ASCII csv format.

Each file contains 15 columns of the considered 15 years (1999-2013) and each column contains a header with the year stamp and 365 (36) lines for the daily (10-daily) files.

The daily files starts on the 1st of January to 31st December, and the 10-daily files dates correspond to the 5, 15 and 25 of each month.

The TimeSeries files contain 3 additional columns where column 16 has the mean value of the 15 years for that day/10-day, column 17 has the corresponding standard deviation for that day/10-day and for comparison purpose, column 18 has the mean value of the 15 years for that day/10-day when no assimilation of the NRT LAI is used.

Examples of files structure:

AnomalyIndex, Drought indicator files

```
    1999 ;»        2000 ;.....;   2013   ;»   (line 1 corresponding to the header)
-4.22353 ;»    -1.70482 ;.....;-0.210518 ;»   (line 2 corresponding to the first day/10-day of the year)
       .  ;»          .  ;.....;      .  ;
       .  ;»          .  ;.....;      .  ;
-1.48786 ;»    -10.6343 ;.....;-10.9844  ;»   (line 366/37 corresponding to the last day/10-day of the year)
```

TimeSeries files:

```
1999 ;      2000 ;......;  2013  ;      Mean ;       STDV ;   Mean_CLM ;  (line 1 corresponding to the header)
-4.22353 ;  -1.70482 ;......;-0.210518 ;  1.77763 ;  0.137406  ;    1.8023 ;  (line 2 corresponding to the first day/10-day of the year)
    .  ;        .  ;......;     .  ;        . ;          . ;         . ;
    .  ;        .  ;......;     .  ;        . ;          . ;         . ;
-1.48786 ;  -10.6343 ;......;-10.9844  ;  1.89718 ;  0.303095  ;   1.97823 ;  (line 366/37 corresponding to the last day/10-day of the year)
```

2.3.3. Spatial coverage

The 85 sites are listed in Table 4 with their coordinates and main vegetation types. They are located in the maps of Figure 3 and Figure 3.

Table 4: Local simulation sites for the ECMWF global LDAS

Site name	latitude	longitude	Veg Type	Network
bondville	40.006	-88.29	crops	CEOP
brasilia	-15.93	-47.92	grass/cerrado	
cabauw	51.971	4.927	Grass	
himalayas-lukla	27.696	86.723	Grass	
himalayas-namch	27.802	86.715	grass	
himalayas-pherich	27.895	86.819	grass	
himalayas-pyram	27.959	86.813	grass	
himalayas-syang	27.81	86.72	grass	
lindenberg-falk	52.167	14.124	grass/crops/forest	
tongyu-crop	44.416	122.867	crops	
tongyu-grass	44.416	122.867	grass	
at-neu	47.12	11.32	grass	FLUXNET
au-how	-12.49	131.15	grass/savannah	
au-fog	-12.54	131.31	grass	
au-otw	-38.532	142.817	crops	
bf-btd	12.46	-1.25	crops	
ch-oe1	47.29	7.73	grass	
ch-oe2	47.286	7.734	crops	
de-geb	51.1	10.914	crops	
de-kli	50.893	13.523	crops	
dk-ris	55.53	12.097	crops	
es-es2	39.28	-0.32	crops	
es-lma	39.942	-5.773	grass/savannah	
es-vda	42.152	1.449	grass	
es-zam	42.933	-2.853	crops	
fi-jok	60.899	23.513	crops	
fr-avi	43.916	4.878	crops	
fr-gri	48.844	1.952	crops	

fr-mau	43.385	1.292	grass	
fr-lq1	45.643	2.736	grass	
hu-mat	47.847	19.726	grass	
hu-bug	46.691	19.601	grass	
ie-ca1	52.859	-6.918	crops	
ie-ca2	52.868	-6.911	grass	
ie-dri	51.987	-8.752	grass	
it-amp	41.9	13.61	grass	
it-bci	40.524	14.957	crops	
it-mbo	46.02	11.05	grass	
it-ca2	42.377	12.026	grass	
it-mal	46.114	11.703	grass	
it-ro3	42.375	11.915	crops	
nl-ca1	51.97	4.93	grass	
nl-haa	52	4.81	grass	
nl-hor	52.03	5.07	grass	
nl-mol	51.95	4.9	crops	
nl-lan	51.65	4.64	grass	
pl-wet	52.762	16.309	grass/wetland	
pt-mi2	38.477	-8.025	grass	
ru-ha1	54.73	90	grass	
ru-ha3	54.7	89.08	grass	
se-deg	64.182	19.557	grass	
us-arm	36.61	-97.49	crops	
us-fr2	29.95	-98	grass/woodland	
us-ib2	41.841	-88.241	grass	
us-lww	34.96	-97.979	grass	
us-srm	31.82	-110.87	grass/savannah	
us-ton	38.43	-120.97	grass/savannah	
us-var	38.41	-120.95	grass/savannah	
us-wkg	31.74	-109.94	grass	
za-kru	-25.02	31.497	grass/savannah	
hu-cso	46.5	20.5	crops	Hungary
hu-bek	46.34	21	crops	
hu-jas	47.06	20.5	crops	
hu-hev	47.78	20.5	Crops	
hu-haj	47.38	21.4	Crops	
hu-sza	47.94	21.5	crops	
hu-fej	46.9	18.7	crops	

hu-kom	47.54	18.2	crops	
hu-heg	46.95	16.65	crops	ImagineS
tu-mer	35.55	9.91	crops/olives	
fr-swe	43.48	1.266	crops	
es-las	39.03	-2.06	crops	
es-car	37.8	-1.05	crops	
es-cor	37.8	-4.73	crops	
es-val	39.26	-0.31	crops	
ke-utb	-0.91	36.8	crops	
za-fsp	-28.416	27.06	grass	
it-ros	45.25	8.55	crops	
uk-psh	50.06	30.1	crops	
ru-tul	53.08	37.23	crops	
ca-gbf	45.3	-75.75	crops	
au-mur	-35.41	146.18	crops/grass	
cl-sfe	-34.7	-70.95	crops	
ar-mlp	-37.9	-67.73	grass/desert	
pe-lam	-6.78	-79.76	crops	

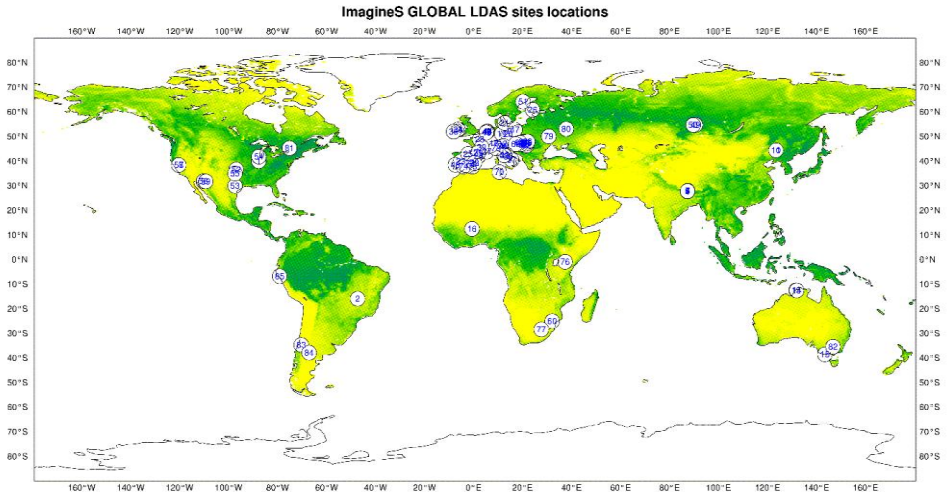

Figure 2: ECMWF global LDAS local simulation sites the Global domain

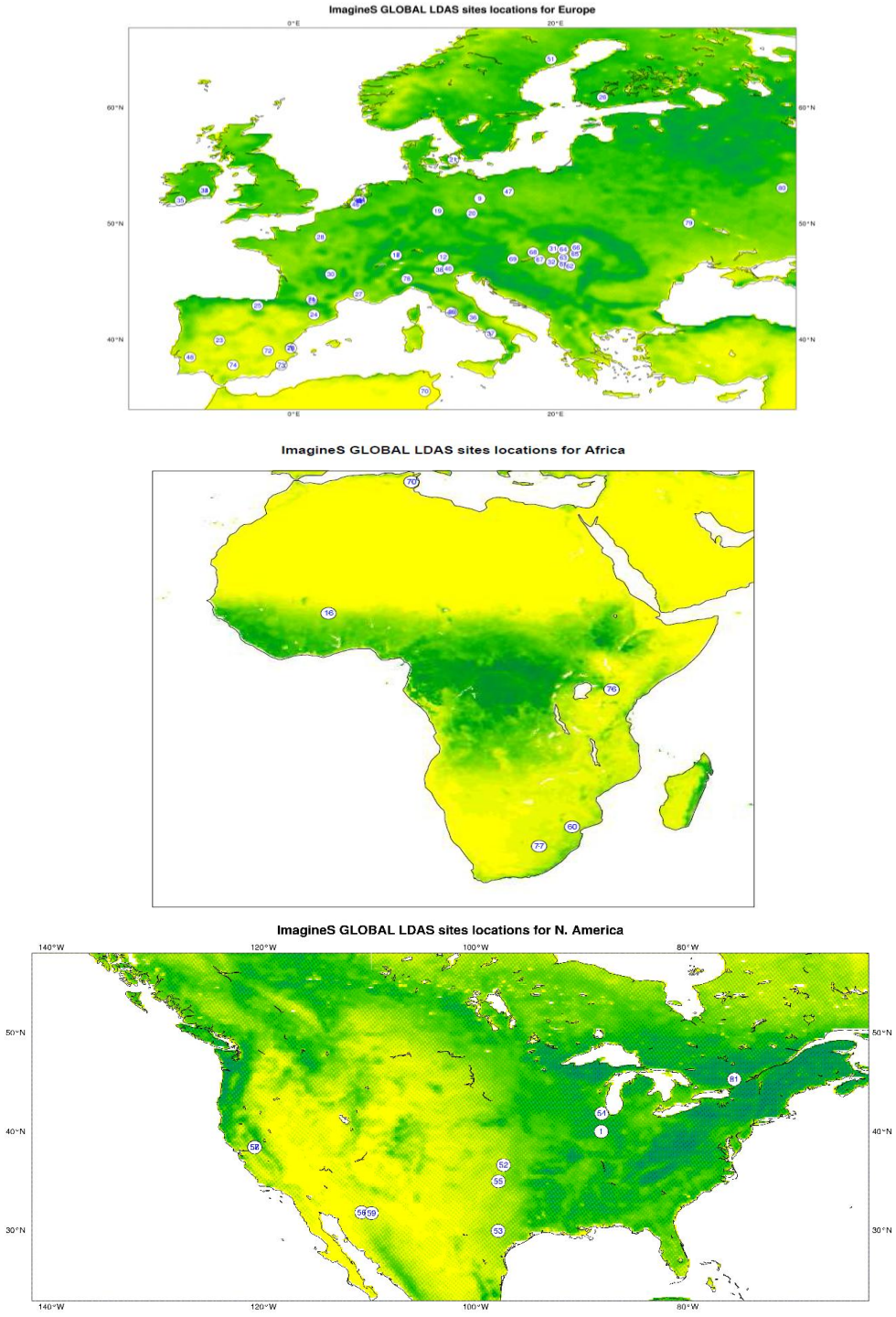

Figure 3: ECMWF global LDAS local simulation sites for: upper panel) Europe, middle panel) Africa, lower panel) North America

2.3.4. Temporal resolution and extent

The global LDAS local simulations are provided in daily and 10-daily time series from 1st January 1999 to 31st December 2013.

2.4. DATA POLICIES

Any use of the LDAS ImagineS products implies the obligation to include in any publication or communication using these products the following citation:

"***The research leading to these results has received funding from the European Community's Seventh Framework Program (FP7/2007-2013) under grant agreement n° 311766. The Global LDAS products are property of ECMWF."***

The users accepts to inform the ImagineS project of their publications through the following address: rl@hygeos.com

2.5. ACCESS AND CONTACT

The global LDAS products are archived under the ECMWF MARS system under the experiment name g9bt. The global data storage is managed by the Meteorological Archiving and Retrieval System available at ECMWF and serves the meteorological users and the member states.

The local simulations are available through the ImagineS website (http://fp7-imagines.eu/pages/services-and-products/ldas-products.php). Connection information to access the products are provided after registration.

Scientific contact: ECMWF

Contact names: Souhail Boussetta & Gianpaolo Balsamo

Emails: souhail.boussetta@ecmwf.int

gianpaolo.balsamo@ecmwf.int

3. SURFEX REGIONAL LDAS

The regional LDAS uses the SURFEX modeling platform (Masson et al., 2013) developed at Meteo-France in collaboration with the HIRLAM and ALADIN meteorological consortia. SURFEX is designed to be coupled to atmospheric and hydrological models. In the LDAS configuration, SURFEX is used offline (i.e. not coupled with the atmosphere) and is driven by gridded atmospheric forcings.

Over France, the model is driven by observation-based atmospheric forcing data which are derived from the SAFRAN (Système d'Analyse Fournissant des Renseignements Atmosphériques à la Neige) meso-scale analysis system at 8-km spatial resolution and hourly temporal sampling (Quintana et al., 2008). Atmospheric variables include precipitation, 2-m air temperature, 2-m specific humidity, wind speed, surface pressure, incoming solar radiation, and incoming long-wave radiation.

Over Hungary, the model is driven by forecasted-based atmospheric forcing data which are derived from the ALADIN-HU cy36t1 numerical weather prediction (NWP) model forecasts (2 m temperature, 2 m specific humidity, pressure, wind speed and rainfall), and LandSAF incoming short and long wave radiation observations at 8-km spatial resolution and hourly temporal sampling.

The LDAS is able to integrate simultaneously available SSM and LAI observations at a given time step into the ISBA-A-gs LSM, aiming at adjusting the model trajectory at that time. ISBA-A-gs represents the vegetation sub-grid heterogeneity (crops, grasslands, coniferous forests, broadleaf forests) by using a mosaic approach (Koster and Suarez, 1992).

The analyzed variables are produced at a temporal scale of three hours. Over a window of 24h, the three-hour output split the window into 8 values. If the assimilation system starts at 9UTC, the first output value in the binary file is three hours later at 12UTC. For fluxes, the last output represents the 24h cumulated values. The specific data assimilation tools (increments, Jacobians, gains, innovations) are written in a daily ASCII format.

The following set of products derived from the analysis (i.e. the model simulation after the assimilation of satellite-derived products) is considered for the ImagineS project:

- LAI, FAPAR and soil moisture
- Total albedo et land surface temperature (LST)
- Evapo-transpiration, drainage, runoff, and carbon fluxes

3.1. THE REGIONAL LDAS CHARACTERISTICS

Table 5 summarizes the characteristics of the regional LDAS-France, and Table 6 summarizes the characteristics of the regional LDAS-Hungary. More details can be found in the Algorithm Theoretical Basis Document [IMAGINES_RP2.1_ATBD_LDAS]

Table 5: Summary of SURFEX regional LDAS-France characteristics

Inputs	Meteorological forcing: SAFRAN Physiographic field (from ECOCLIMAP II, SIM) Copernicus Global Land GEOV1 LAI product. Copernicus Global Land ASCAT SWI-001 surface soil moisture.
Outputs	Analyzed LAI, Root-zone soil moisture (WG2), NEE, GPP, Evapo-transpiration, at a spatial resolution of 8 km x 8 km
Interfaces	Copernicus Global Land service (http://land.copernicus.eu/global) Météo-France operational SAFRAN production.
Capacity requirements	1 dedicated desktop computer. About 50 Go per year (including output products, inputs and auxiliary variables)

Table 6: Summary of SURFEX regional LDAS-Hungary characteristics

Inputs	Meteorological forcing: ALADIN-HU model outputs (2 m temperature, pressure, wind speed and rainfall) + LandSAF incoming short and long wave radiation observations Physiographic field (from ECOCLIMAP II, FAO, GTOPO30) Copernicus Global Land GEOV1 LAI product. Copernicus Global Land ASCAT SWI-001 surface soil moisture.
Outputs	Analyzed LAI, Root-zone soil moisture (WG2), NEE, GPP, Evapo-transpiration, at a spatial resolution of 8 km x 8 km
Interfaces	Copernicus Global Land service (http://land.copernicus.eu/global) OMSZ ALADIN-HU forecasts
Capacity requirements	IBM iDATAPLEX Linux cluster About 3 Go per year (including output products, inputs and auxiliary variables)

3.2. PRODUCT DESCRIPTION

3.2.1. Variables

The daily analyzed variables given by the regional LDAS are:

- LAI (m^2 m^{-2})
- SWI (dimensionless root-zone soil moisture, SWI=0 for wilting point, and SWI=1 at field capacity)
- Evapotranspiration (kgH2O m^{-2} day^{-1})
- NEE (kgCO2 m^{-2} day^{-1})
- GPP (kgCO2 m^{-2} day^{-1})
- Above-ground biomass (ABG) anomaly (% difference w.r.t. the 2008-2013 mean at the same date)

The above-ground biomass anomaly is the % difference w.r.t. the 2008-2013 mean at the same date and is expressed as the anomaly of ABG_i for a particular day i with regard to its 2008-2013 average $\overline{ABG}_{i,2008\text{-}2013}$ for the same period i. It is formulated as:

$$AI_{ABG} = \frac{ABG_i - \overline{ABG}_{i,2008\text{-}2013}}{\overline{ABG}_{i,2008\text{-}2013}} * 100 .$$

10-daily time series of drought indicators:

These time series consist of scaled anomalies for a given 10-daily period for above-ground biomass, LAI and root-zone soil moisture (see Eq. (2) in Szczypta et al. 2014).

The drought indicator is a scaled anomaly index of a parameter V_i for a particular 10-day period i with regard to its standard deviation σ_{V_i} over the 2008-2013 period. It follows Szczypta et al. 2014 and is expressed as

$$DI_V = \frac{V_i - \overline{V}_{i,2008\text{-}2013}}{\sigma_{V_i}},$$

where $\overline{V}_{i,2008\text{-}2013}$ is the average value for 10-day i over the 2008-2013 period.

The anomaly indicators are provided from January to December (i.e. thirty six 10-daily periods).

The 10-daily drought indicators are listed below:

- Above-ground biomass scaled anomaly
- LAI scaled anomaly
- SWI scaled anomaly

3.2.2. Folder and Files content

The regional LDAS products are provided into 2 folders named, respectively, France and Hungary. Each folder contains .zip archives, one per vegetation type (see 3.2.4), which include a set of 9 files, the 6 daily analyzed variables and the 10-daily time series of 3 drought indicators.

The lat/lon coordinates of the model grid-cells (each grid-cell corresponds to a column in the files (see 3.2.3)) are given in coordinate files named as

DepartementCoordinates_<Country>_<VegetationType>.csv

where <Country> and <VegetationType> are following §3.2.4

In these files, the administrative units of France (“department”) are listed by numerical order of the département numbers. These numbers, together with a map of the departments, can be found on: https://en.wikipedia.org/wiki/Departments_of_France.

The locations (“lat,lon”) are those selected by Calvet et al. (2012) and correspond to SAFRAN grid cells presenting more than 45% of either C3 crops (45 grid cells) or grasslands (48 grid cells) below 1000m above sea level, according to the fractions of vegetation types derived from ECOCLIMAP-II (Faroux et al. 2013). The coordinate files contain the latter ("fraction_ECOCLIMAP2").

For Hungary, the administrative units are list by numerical order of the county numbers, related to the alphabetical order of the counties. These numbers, together with a map of the counties, can be found on: https://en.wikipedia.org/wiki/Counties_of_Hungary.

3.2.3. File Format

The files are provided in ASCII csv format and can be read with any file reader system, including excel.

The format of columns is:

date (YYYY-MM-DD), value grid-cell 1, value grid-cell 2, etc.

with DD is from 01 to 31 for daily time series, and DD= 03, 13 or 23 for 10-daily time series of drought indicators

In these files, the first (second, third, ...) column (value grid-cell) after the date corresponds to the département described by the first (second, third, ...) line of the coordinate file (see 3.2.2) and listed in Table 8 and Table 9. Note that a given département may be present in the straw cereal files and in the grassland files, but not at the same location.

Examples:

- file *LDAS_France_StrawCereals_daily_AGB.csv* :

2008-01-01,-30.952025827970544,-8.55408485581949,-20.456057681835745, …

-30.952025827970544 is the value of Above Ground Biomass anomaly for the site located at 49.83°N, 3.06°E in département n°2 (Aisne) on 1st January 2008.

- file *LDAS_France_Grasslands_drought_indicator_LAI.csv*:

2010-05-13,-1.0738979778762379,-0.1769208658659556,-0.861806536944218 ….

-0.861806536944218 is the value of the LAI scaled anomaly (drought indicator) for the site located at 49.74°N, 2.81°E in department n°8 (Ardennes) on 13th of May 2010.

- File *LDAS_Hungary_StrawCerals_daily_NEE.csv* :

2009-09-19,0.0026325254050820,0.0072379636104260,0.0166126969955700, …

0.0072379636104260 is the value of the NEE for the site located at 46.50°N, 20.50°E in county n°5 (Csongrad) on 19th September 2009.

Examples of temporal profiles over France are given in Annex 1: Temporal profiles of regional LDAS-France products and example maps are showed in Annex 2: Example maps of regional LDAS-France products

Examples of temporal profiles over Hungary are given in Annex 3: Temporal profiles regional LDAS-Hungary products and example maps are showed in Annex 4: Example maps of regional LDAS-Hungary products

3.2.4. File naming

The file naming is compliant with the following convention:

LDAS_<Country>_<VegetationType>_daily_<ACRONYM>.csv

LDAS_<Country>_<VegetationType>_drought_indicator_<ACRONYM>.csv

where

- <Country> stands for “France” or “Hungary”
- <VegetationType> is “StrawCereals” or “Grasslands”
- <ACRONYM> is the abbreviation of the variable (Table 7).

Note that, for Hungary, products are provided only for “StrawCereals”.

Table 7: Acronyms and units of the regional LDAS variables

Product name	Abreviation	Units
Leaf Area Index	LAI	$m^2\ m^{-2}$
Root-zone soil wetness index	SWI	-
Evapotranspiration	ETR	$kgH_2O\ m^{-2}\ d^{-1}$
Net Ecosystem Exchange	NEE	$kgCO_2\ m^{-2}\ d^{-1}$
Gross primary production	GPP	$kgCO_2\ m^{-2}\ d^{-1}$
Above ground biomass anomaly	AGB	%

3.2.5. Spatial coverage

The daily analyzed variables and drought indicators are provided for the grid cells corresponding to 45 locations of straw cereal crops (Table 8), plus 48 additional grid-cells for grasslands (Table 9) over France (Figure 4).

They are provided for the grid cells corresponding to 8 locations of straw cereals crops, plus the Hegyhatsal site, over Hungary (Table 10 and Figure 5).

Table 8: LDAS-France 45 straw cereal simulation sites

Département	Latitude	Longitude	C3 crop fraction in ECOCLIMAP2
02	49.83	3.06	0.704
03	46.09	3.22	0.566

08	49.6	4.16	0.671
09	43.28	1.30	0.457
11	43.21	2.09	0.654
16	46.07	0.11	0.497
17	46.04	-0.92	0.595
18	47.17	1.86	0.614
21	47.21	5.14	0.605
24	44.71	0.57	0.529
27	49.17	0.53	0.697
28	48.1	1.85	0.698
31	43.57	1.79	0.660
32	43.71	1.00	0.655
36	46.95	1.13	0.665
37	47.66	0.58	0.639
39	46.99	5.34	0.635
41	47.96	1.53	0.670
45	48.18	2.07	0.672
49	47.51	0.16	0.600
51	49.32	3.71	0.680
52	48.65	4.78	0.579
54	49.2	5.90	0.591
55	48.71	5.43	0.579
57	49.19	6.23	0.558
58	47.45	3.13	0.582
59	50.04	3.29	0.685
60	49.68	3.06	0.692
61	48.67	0.76	0.685
62	50.19	2.95	0.728
63	45.94	3.21	0.644
70	47.49	5.47	0.531
71	46.92	5.02	0.559
72	47.95	0.78	0.650
77	48.82	3.26	0.675
78	48.89	1.63	0.651
79	46.14	0.01	0.587
80	49.97	2.39	0.709
81	43.64	1.79	0.658
82	43.85	1.00	0.586
85	46.4	-1.04	0.589
86	46.58	0.72	0.626
89	47.53	3.24	0.630
91	48.32	2.28	0.660
95	49.18	1.73	0.658

Table 9: LDAS-France 48 grassland simulation sites

Département	Latitude	Longitude	Grassland fraction in ECOCLIMAP2
02	49.96	3.95	0.685
03	46.59	2.81	0.748
08	49.74	4.28	0.649
12	44.07	2.59	0.699
14	49.23	-0.02	0.758
15	44.72	2.29	0.715
16	45.93	0.74	0.698
17	45.82	-1.01	0.488
18	46.66	2.18	0.742
19	45.44	1.67	0.754
21	47.22	4.40	0.686
22	48.4	-3.34	0.568
23	46.37	1.56	0.751
24	45.44	1.16	0.714
27	49.24	0.42	0.516
29	48.44	-3.88	0.575
31	43.12	0.52	0.534
35	48.48	-1.29	0.628
36	46.45	1.97	0.743
42	46	4.25	0.735
44	47.23	-1.94	0.533
46	44.79	1.78	0.699
49	47.63	-0.80	0.530
50	49.05	-1.33	0.791
51	49.01	5.02	0.483
52	48.13	5.62	0.694
53	48.49	-0.96	0.627
54	48.41	6.07	0.56
55	49.58	5.38	0.519
56	48.17	-3.53	0.511
58	46.87	4.07	0.720
59	50.03	3.95	0.767
61	48.95	0.21	0.690
63	46.23	2.91	0.730
64	43.3	-1.26	0.604
69	46.28	4.57	0.671
70	47.68	6.23	0.527
71	46.22	3.94	0.749
72	48.3	-0.09	0.510
76	49.68	1.51	0.654
79	47.06	-0.45	0.53
81	44.07	2.39	0.624

82	44.22	1.79	0.458
85	46.89	-1.50	0.530
86	46.3	0.94	0.698
87	46.23	1.14	0.747
88	48.34	5.95	0.588
89	47.37	3.87	0.668

Table 10: LDAS-Hungary 8 straw cereal simulation sites + Hegyhátsál (17. Ad. unit)

Administrative unit	Latitude	Longitude	C3 crop fraction in ECOCLIMAP2
03	46.34	21.00	0.329
05	46.50	20.50	0.449
06	46.90	18.70	0.488
08	47.38	21.40	0.106
09	47.78	20.50	0.362
10	47.06	20.50	0.428
11	47.54	18.20	0.269
15	47.94	21.50	0.259
17	46.98	16.70	0.338

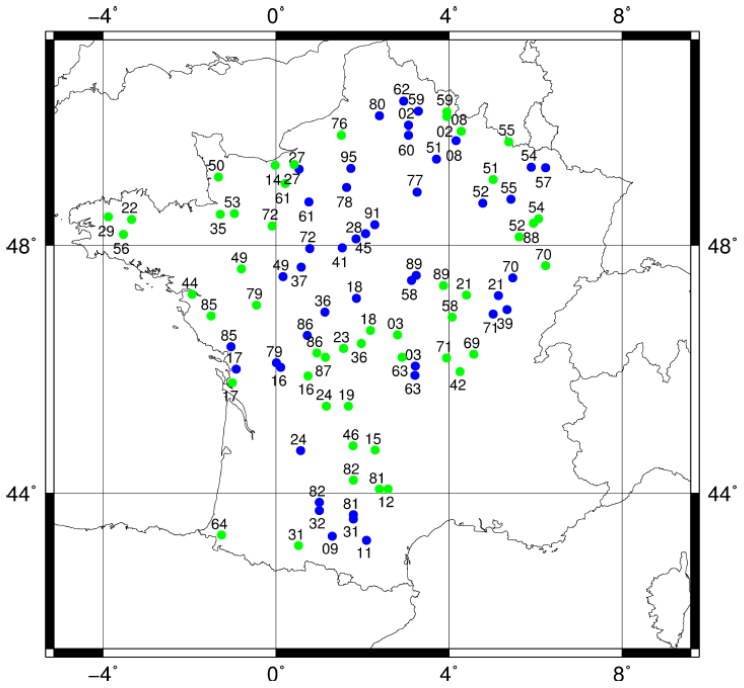

Figure 4: LDAS-France local simulation sites: 45 cropland and 48 grassland 8 km x 8 km grid cells (blue and green dots, respectively) and the corresponding département number (from Canal et al., 2014).

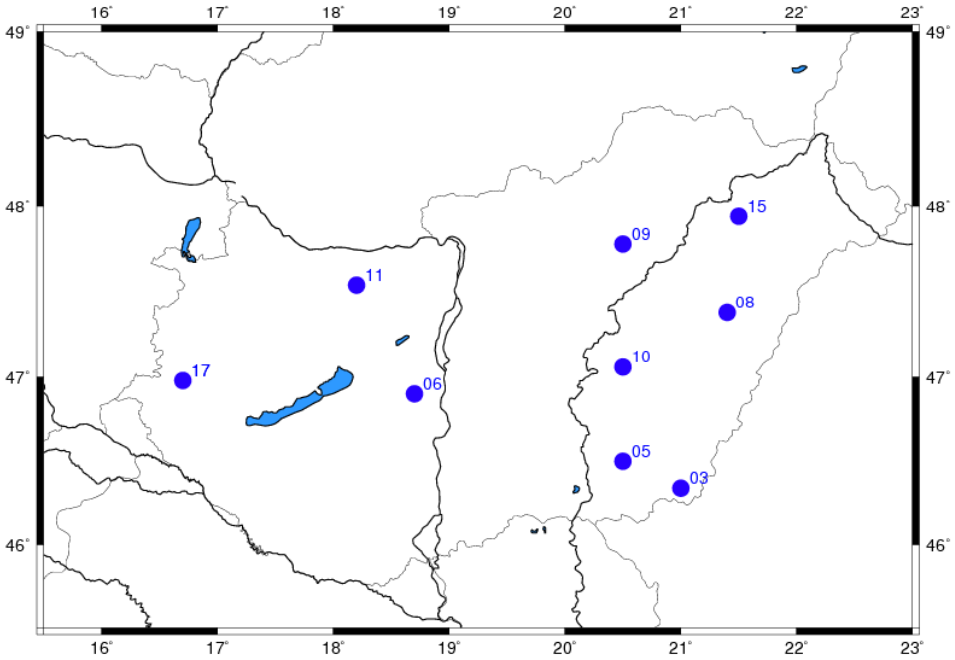

Figure 5: LDAS-Hungary local simulation sites: 9 cropland 8 km x 8 km grid cells.

3.3. DATA POLICIES

Any use of the regional LDAS ImagineS products implies the obligation to include in any publication or communication using these products the following citation:

- For the LDAS-France products:

"***The research leading to these results has received funding from the European Community's Seventh Framework Program (FP7/2007-2013) under grant agreement n° 311766. The LDAS products over France are property of Meteo-France."***

- For the LDAS-Hungary products:

"The research leading to these results has received funding from the European Community's Seventh Framework Program (FP7/2007-2013) under grant agreement n° 311766. The LDAS products over Hungary are property of OMSZ."

The users accepts to inform the ImagineS project of their publications through the following address: rl@hygeos.com

3.4. ACCESS AND CONTACT

The regional LDAS products are available through the ImagineS website (http://fp7-imagines.eu/pages/services-and-products/ldas-products.php). Connection information to access the products are provided after registration.

Scientific contact LDAS-France product: METEO-France

Contact name: Jean-Christophe Calvet

Email: jean-christophe.calvet@meteo.fr

Scientific contact LDAS-Hungary products: OMSZ

Contact name: Helga Toth

Email: toth.h@met.hu

4. QUALITY ASSESSMENT

4.1. GLOBAL LDAS PRODUCTS

The validation of the Global LDAS was based on exploring the benefits of assimilating LAI, and albedo products in conjunction with the soil moisture products for agriculture and drought monitoring on one hand, and near surface forecast improvement within NWP systems on the other hand. It was shown that assimilating the IMAGINES products:

i) Improves the correlation of the biomass outputs with the WOFOST products,

ii) The indices derived from the LDAS can be used to monitor drought and extreme events at the global and regional scales,

iii) An overall positive impact is obtained on the near-surface air temperature and humidity especially in areas where the LAI anomaly is pronounced driven by an improvement in the surface fluxes estimation.

More details can also be found in the validation report of the global LDAS products [IMAGINES_RP7.4_VR_LDAS-Global] and in Boussetta et al. 2014, Boussetta et al. 2015a and Boussetta et al. 2015b.

4.2. REGIONAL LDAS-FRANCE PRODUCTS

A validation methodology was implemented and focused on 1) above-ground biomass and LAI and 2) river discharges. The LDAS performance for straw cereals was tested against the Agreste agricultural data and simulations from the WOFOST crop model. It was shown that a significant improvement is obtained by using the LDAS chain. Next the validation focus is on the river discharges. While the assimilation of ASCAT SSM data is more problematic for the water balance showing an overestimation of drainage fluxes in winter, the assimilation of LAI only has generally a positive impact on the evapo-transpirations fluxes which leads to improvements in terms of river discharges.

More details can also be found in the validation report of the regional LDAS-France products [IMAGINES_RP7.4_VR_LDAS-France].

4.3. REGIONAL LDAS-HUNGARY PRODUCTS

A validation methodology was implemented and focused on above-ground biomass, LAI SWI, WG2 and water- and CO_2 fluxes. Open-loop (Surfex run without assimilation) and LDAS runs were compared with each other and against the satellite measurements (GEOV1 LAI and SWI). The LDAS performance for straw cereals was tested against the Central Statistical Office agricultural data and simulations from the WOFOST crop model. It was shown that a significant improvement is obtained by using the LDAS chain.

More details can also be found in the validation report of the regional LDAS-Hungary products [IMAGINES_RP7.4_VR_LDAS-Hungary].

5. REFERENCES

Balsamo, G., P. Viterbo, A. Beljaars, B. van den Hurk, M. Hirschi, A.K. Betts, and K. Scipal, 2009: A Revised Hydrology for the ECMWF Model: Verification from Field Site to Terrestrial Water Storage and Impact in the Integrated Forecast System. J. Hydrometeor., 10, 623-643.

Balsamo, G., S. Boussetta, E. Dutra, A. Beljaars, P. Viterbo, B. Van den Hurk, 2011: Evolution of land surface processes in the IFS, ECMWF Newsletter, 127, 17-22.

Boussetta, S., Balsamo, G., Beljaars, A., Kral, T. & Jarlan, L. 2013a: Impact of a satellite-derived Leaf Area Index monthly climatology in a global Numerical Weather Prediction model, Int. J. Rem. Sens., 34 (9-10), 3520-3542.

Boussetta, S. et al., 2013b: Natural land carbon dioxide exchanges in the ECMWF Integrated Forecasting System: Implementation and Offline validation. J. Geophys. Res. 118, 1-24. doi:10.1002/jgrd.50488.

Boussetta, S. Balsamo, G., Beljaars A., Dutra E., Albergel C., 2014: Analysis of surface albedo and Leaf Area Index from satellite observations and their impact on numerical weather prediction. ECMWF Tech. Memo. 740 (http://old.ecmwf.int/publications/library/ecpublications/_pdf/tm/701-800/tm740.pdf).

Boussetta, S., Balsamo, G., Dutra, E., Beljaars, A., Albergel, C., 2015a: Assimilation of surface albedo and vegetation states from satellite observations and their impact on numerical weather prediction, Remote Sensing of Environment, Volume 163, 15 June 2015, Pages 111-126, ISSN 0034-4257, http://dx.doi.org/10.1016/j.rse.2015.03.009.

Boussetta, S., Balsamo, G., Dutra, E., Beljaars, A., Albergel, C., De Rosnay P., and Munoz-Sabater, J., 2015b: Impact of vegetation cover variability on surface energy and carbon fluxes. European Geosciences Union General Assembly 2015, Vienna; 04/2015.), (http://presentations.copernicus.org/EGU2015-14931_presentation.pdf).

Calvet, J.-C., Lafont, S., Cloppet, E., Souverain, F., Badeau, V., and Le Bas, C., 2012: Use of agricultural statistics to verify the interannual variability in land surface models: a case study over France with ISBA-A-gs, Geosci. Model Dev., 5, 37–54, doi:10.5194/gmd-5-37-2012.

Canal, N., J.-C. Calvet, B. Decharme, D. Carrer, S. Lafont, and G. Pigeon, 2014: Evaluation of root water uptake in the ISBA-A-gs land surface model using agricultural yield

statistics over France, Hydrol. Earth Syst. Sci., 18, 4979–4999, doi:10.5194/hess-18-4979-2014.

Faroux, S., Kaptue Tchuente , A. T., Roujean, J.-L., Masson, V., Martin, E., and Le Moigne, P., 2013: ECOCLIMAP-II/Europe: a twofold database of ecosystems and surface parameters at 1 km resolution based on satellite information for use in land surface, meteorological and climate models, Geosci. Model Dev., 6, 563–582, doi:10.5194/gmd-6-563-2013.

Gu, Y., Belair, S., Mahfouf, J. F., and Deblonde, G., 2006: Optimal interpolation analysis of leaf area index using MODIS data, Remote Sens. Environ., 104, 283–296, doi:10.1016/j.rse.2006.04.021.

Koster, R. D. and Suarez, M. J., 1992: Modeling the land surface boundary in climate models as a composite of independent vegetation stands, J. Geophys. Res., 97, 2697–2715.

Masson, V., et al., 2013: The SURFEXv7.2 land and ocean surface platform for coupled or offline simulation of earth surface variables and fluxes, Geosci. Model Dev., 6, 929–960, doi:10.5194/gmd-6-929-2013.

Quintana-Segui, P., Lemoigne, P., Durand, Y., Martin, E., Habets, F., Baillon, M., Canellas, C., Franchisteguy, L., and Morel, S., 2008: Analysis of near surface atmospheric variables: Validation of the SAFRAN analysis over France, J. Appl. Meteorol. Clim., 47, 92–107.

Szczypta, C., Calvet, J.-C., Maignan, F., Dorigo, W., Baret, F., and Ciais, P., 2014: Suitability of modelled and remotely sensed essential climate variables for monitoring Euro-Mediterranean droughts, Geosci. Model Dev., 7, 931-946, doi:10.5194/gmd-7-931-2014.

ANNEX 1: TEMPORAL PROFILES OF REGIONAL LDAS-FRANCE PRODUCTS

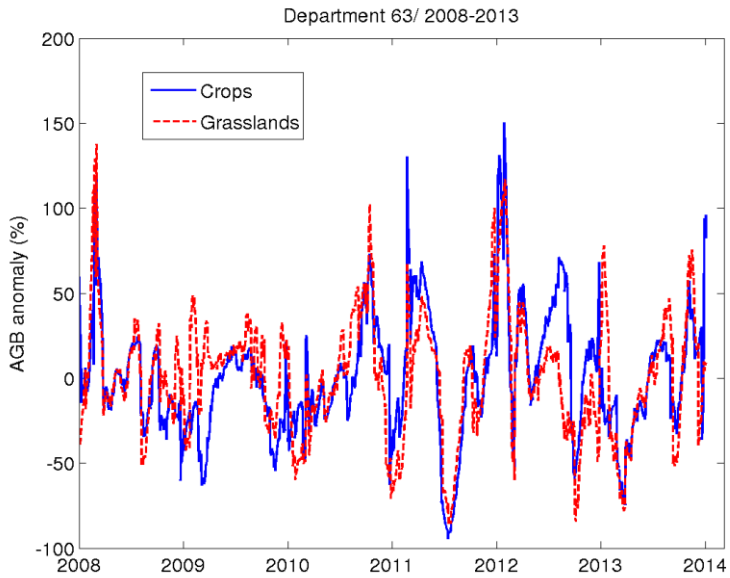

Figure 6: Above ground biomass anomaly for Puy-de-Dôme (département "63") at two locations, indicated in Table 8 for straw cereals and in Table 9 for grasslands (blue and red lines, respectively).

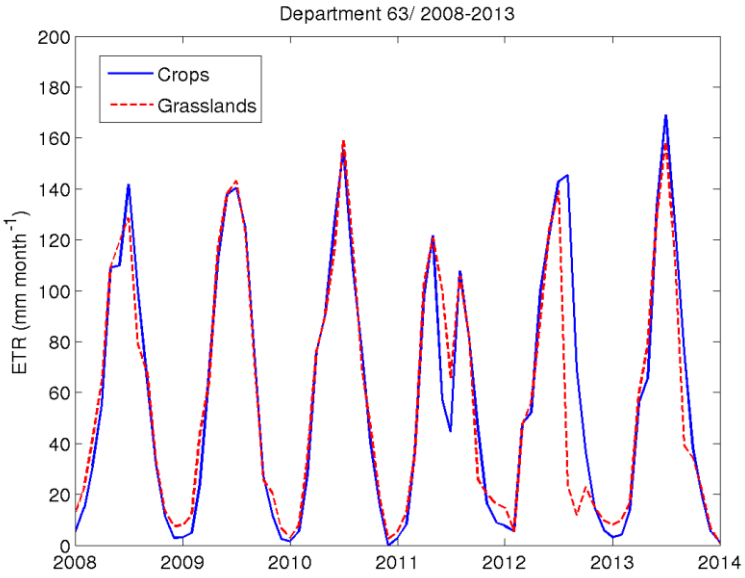

Figure 7: As in Figure 6 for evapotranspiration (monthly accumulated values).

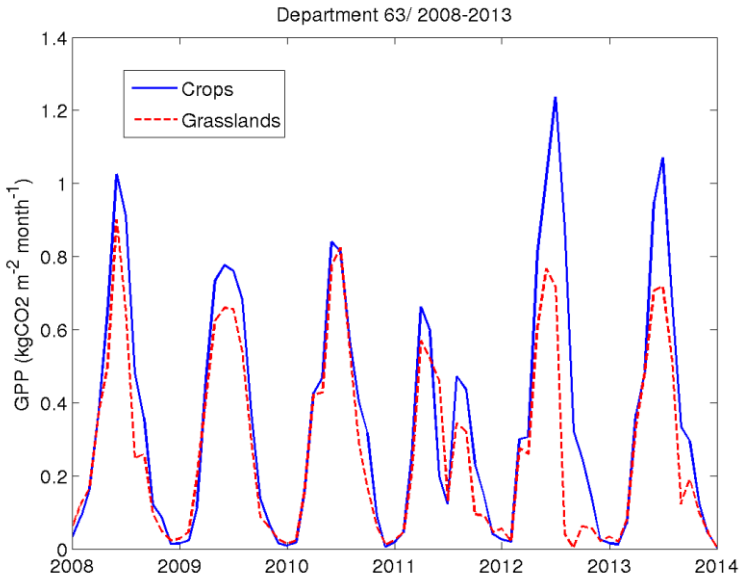

Figure 8: As in Figure 6 for gross primary production (monthly accumulated values).

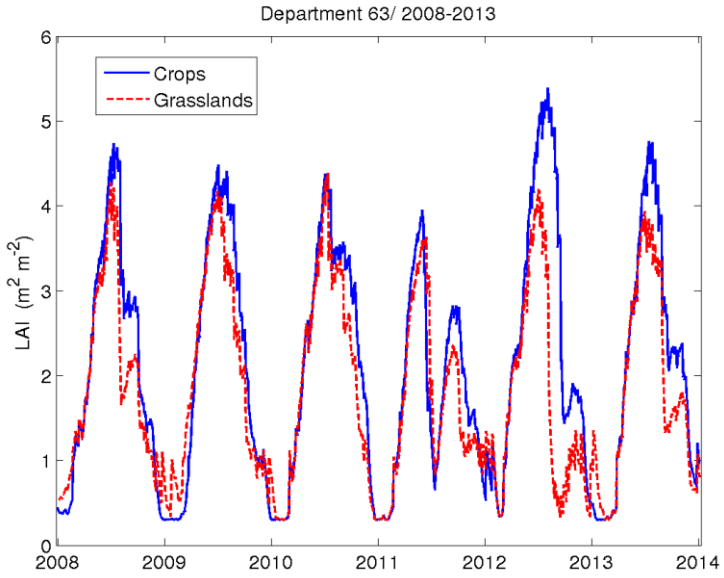

Figure 9: As in Figure 6 for Leaf Area Index.

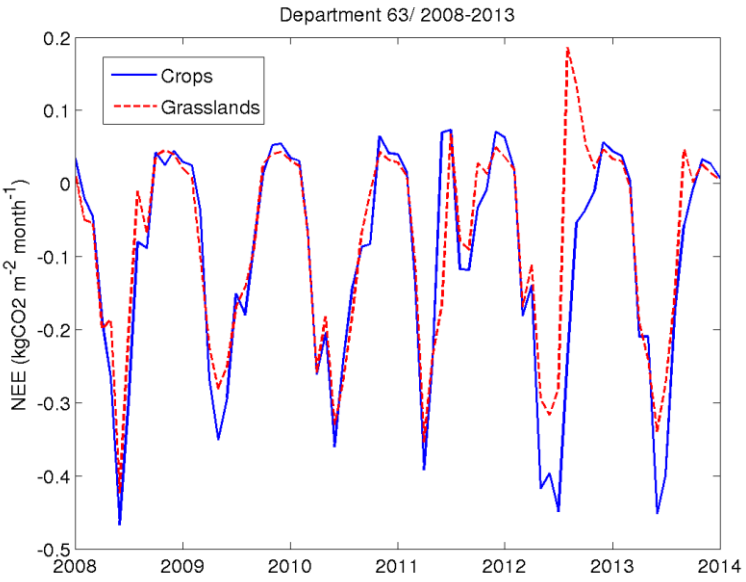

Figure 10: As in Figure 6 for Net Ecosystem Exchange of CO_2 (monthly accumulated values).

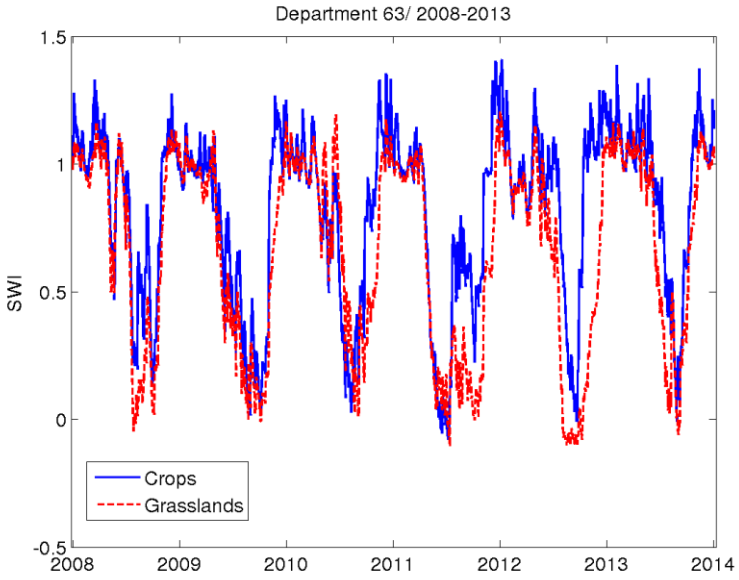

Figure 11: As in Figure 6 for Soil Wetness Index.

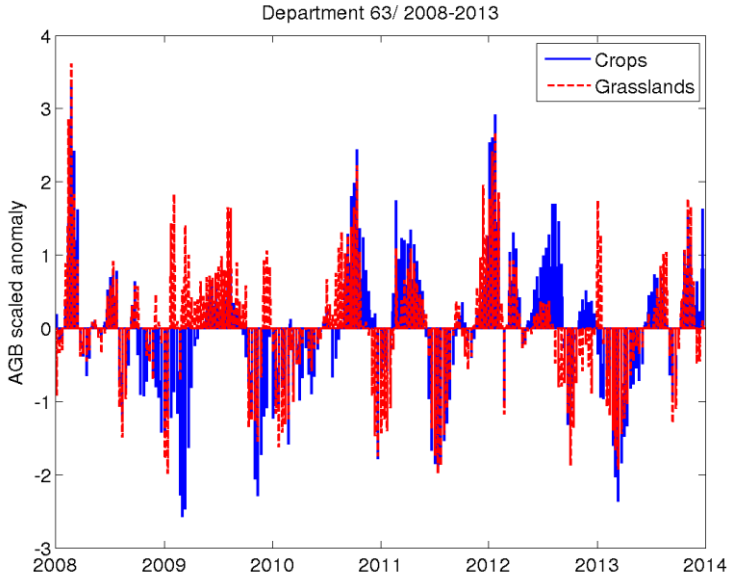

Figure 12: As in Figure 6 for AGB based drought indicator.

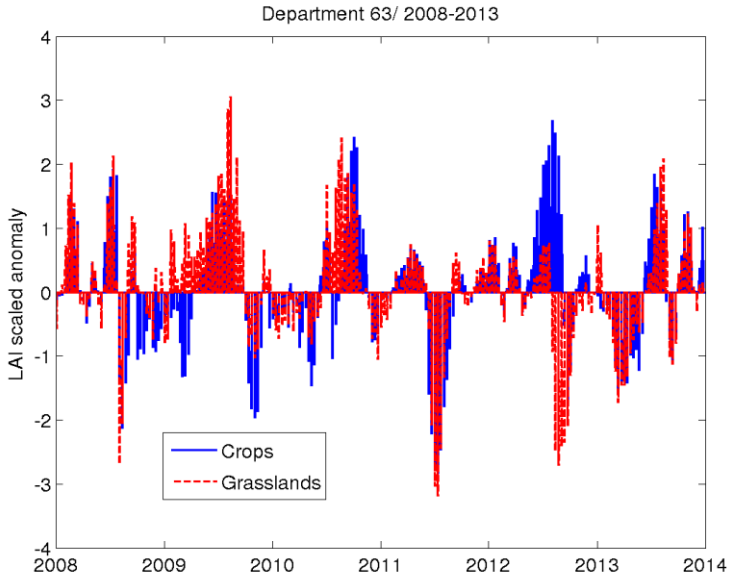

Figure 13: As in Figure 6 for LAI based drought indicator.

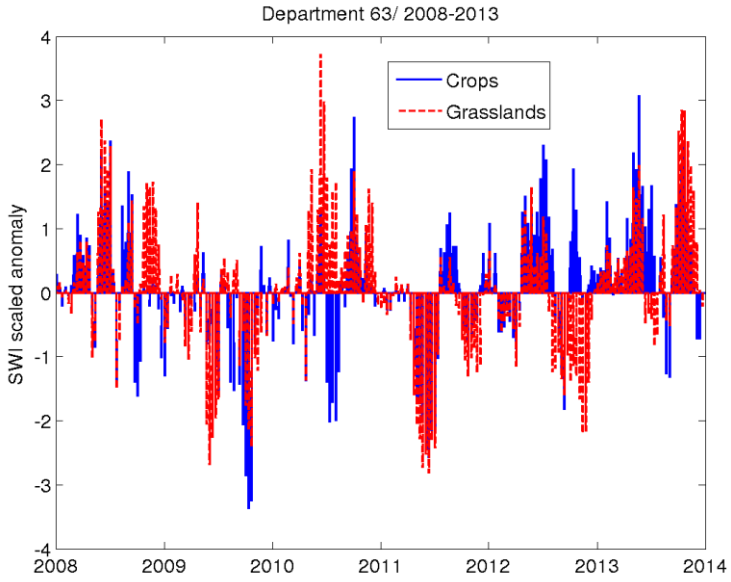

Figure 14: As in Figure 6 for SWI based drought indicator.

ANNEX 2: EXAMPLE MAPS OF REGIONAL LDAS-FRANCE PRODUCTS

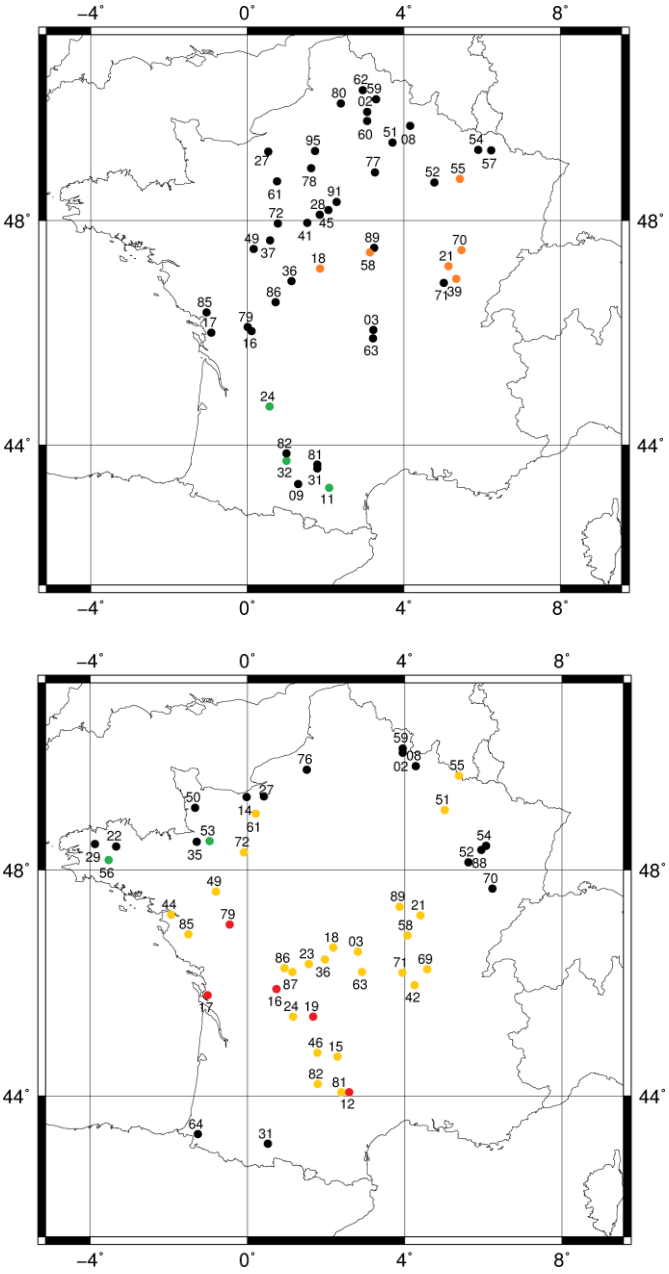

Figure 15: Map of the AGB based drought indicator (DI_{AGB}) for straw cereals on 23 May 2013 (top) and grasslands on 13 July 2011 (bottom) over France. Green dots are for positive DI_{AGB} values, dark dots for DI_{AGB} values between -1 and 0, orange dots for DI_{AGB} values between -2 and -1, red dots for DI_{AGB} values between -3 and -2.

ANNEX 3: TEMPORAL PROFILES REGIONAL LDAS-HUNGARY PRODUCTS

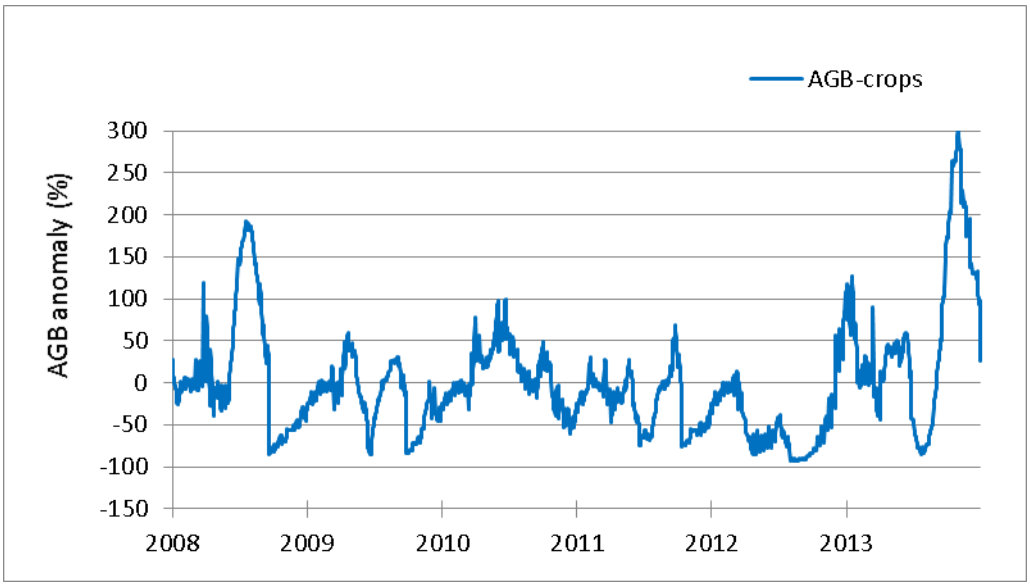

Figure 16: Above ground biomass anomaly for Jász-Nagykun-Szolnok (administrative unit "10") at one location, indicated in Table 12

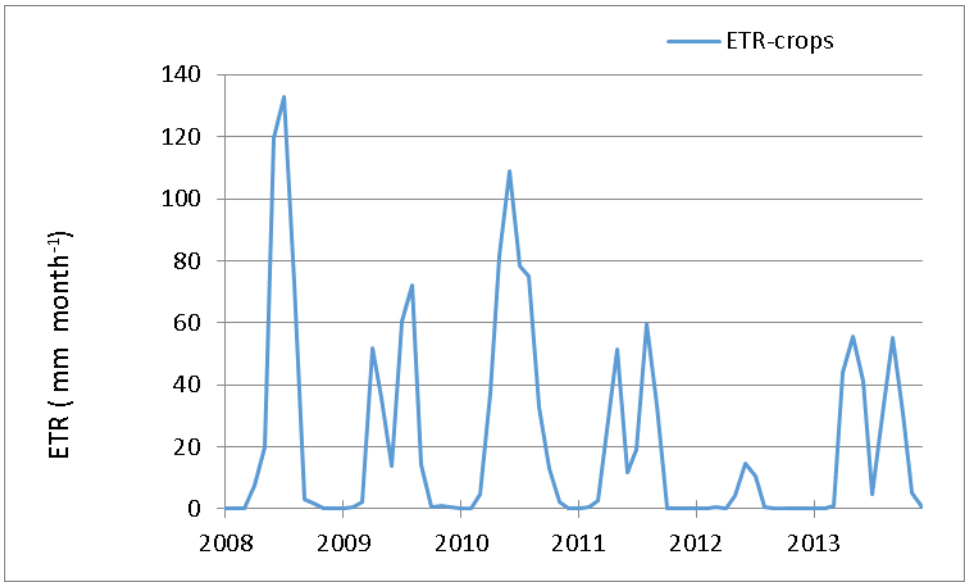

Figure 17: As in Figure 16 for the Evapotranspiration (monthly accumulated values).

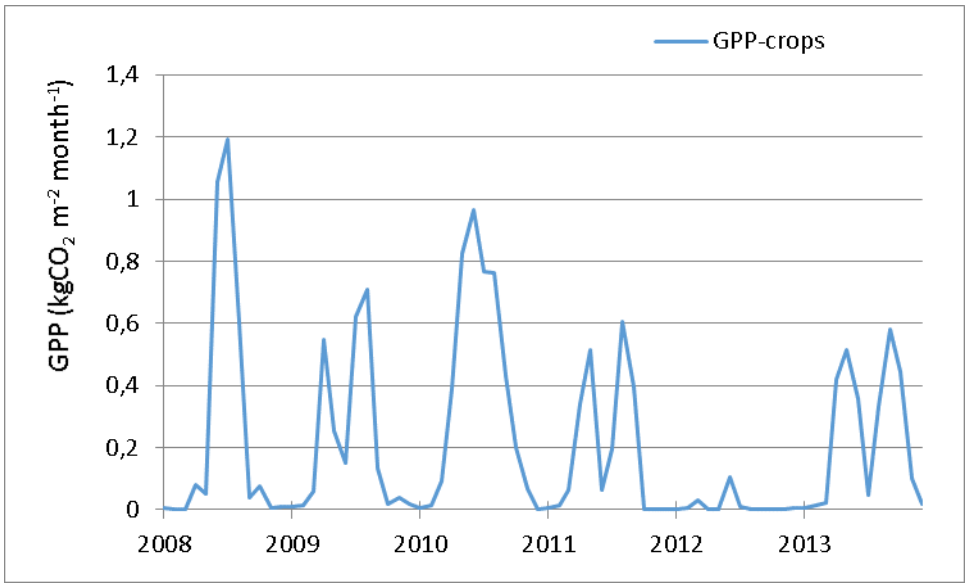

Figure 18: As in Figure 16 for gross primary production (monthly accumulated values)

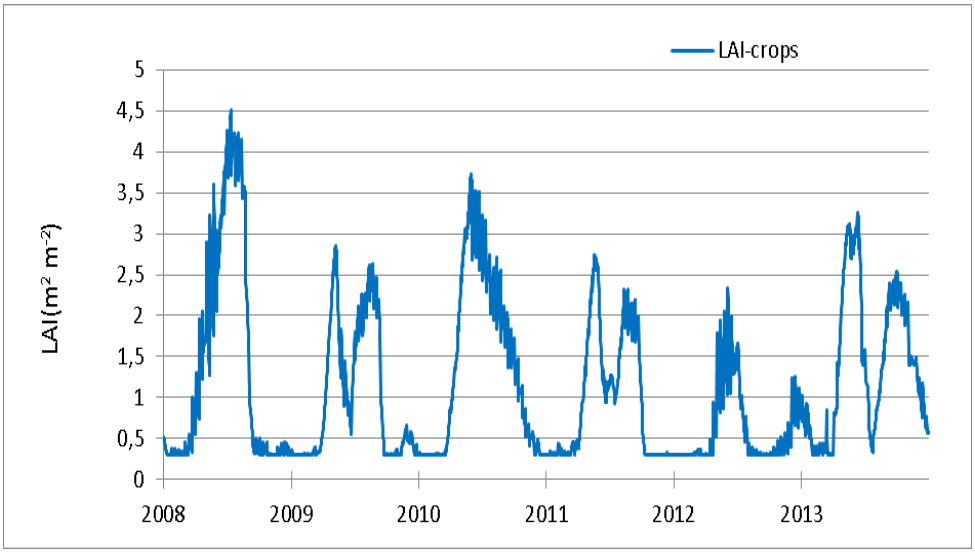

Figure 19: As in Figure 16 for leaf area index

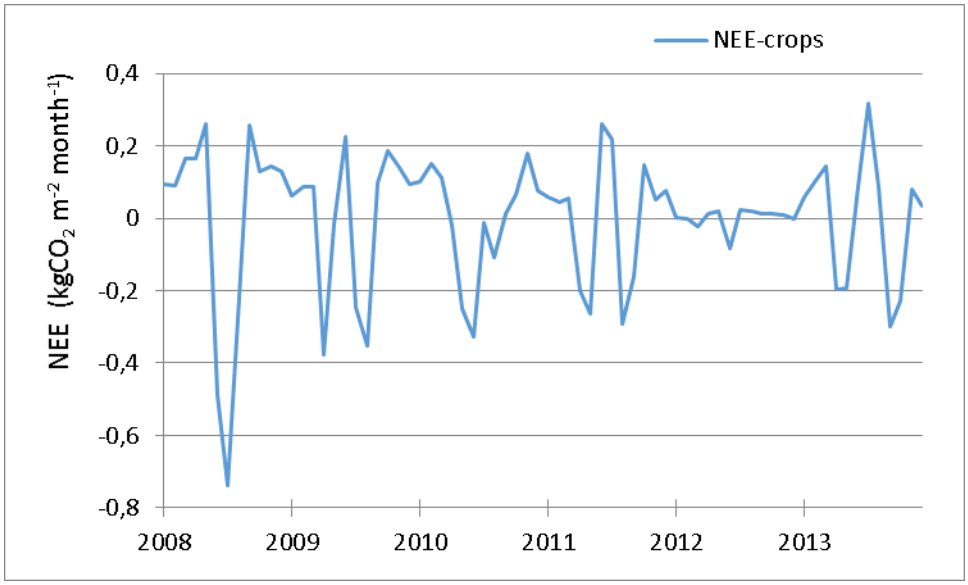

Figure 20: As in Figure 16 for net ecosystem exchange of CO_2 (monthly accumulated values)

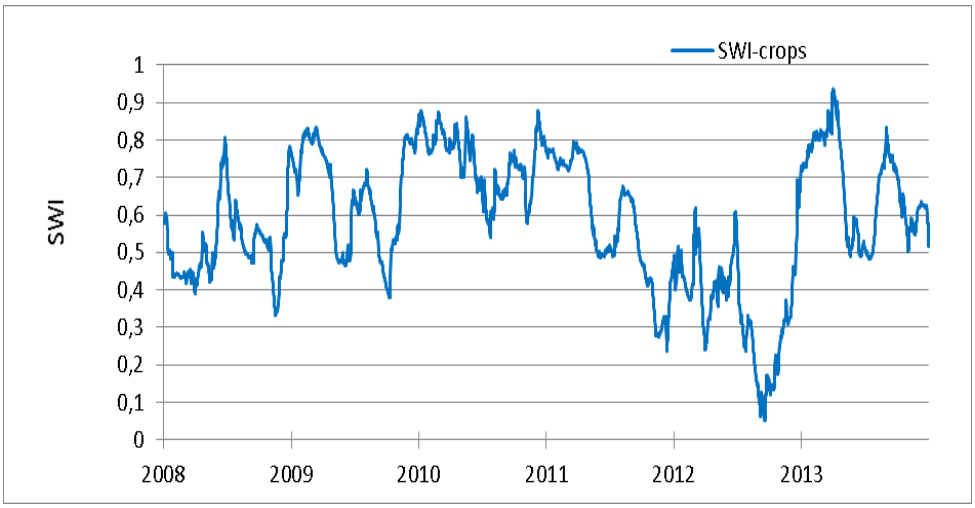

Figure 21: As in Figure 16 for soil wetness index

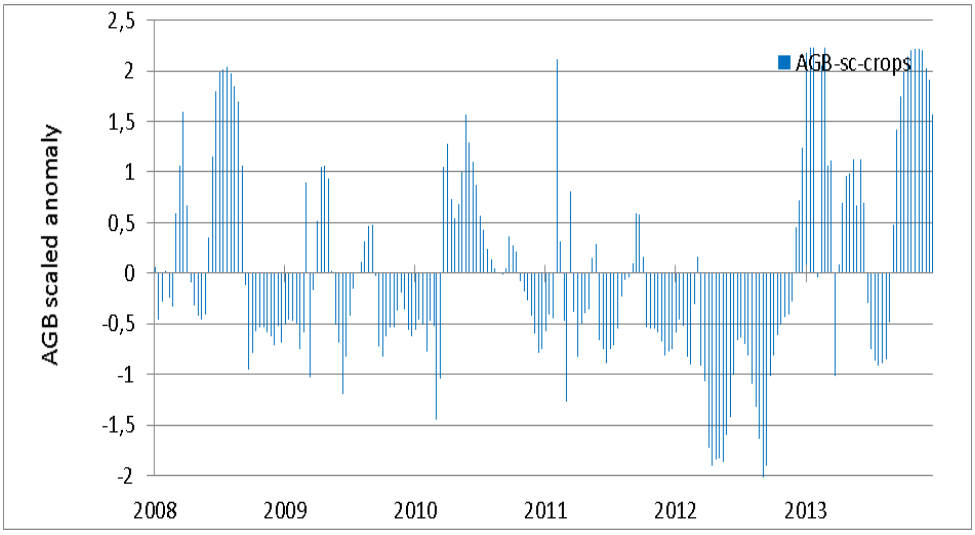

Figure 22: As in Figure 16 for AGB based drought indicator

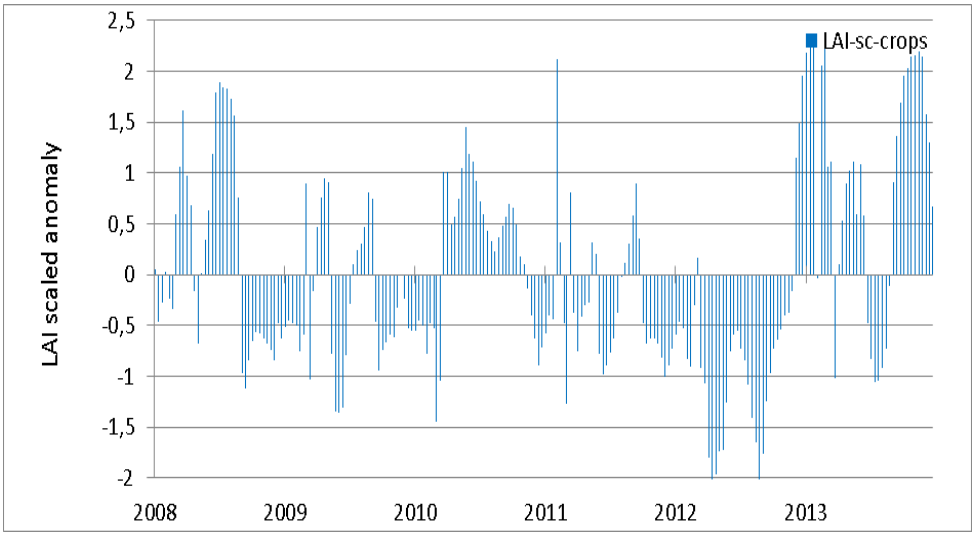

Figure 23: As in Figure 16 for LAI based drought indicator

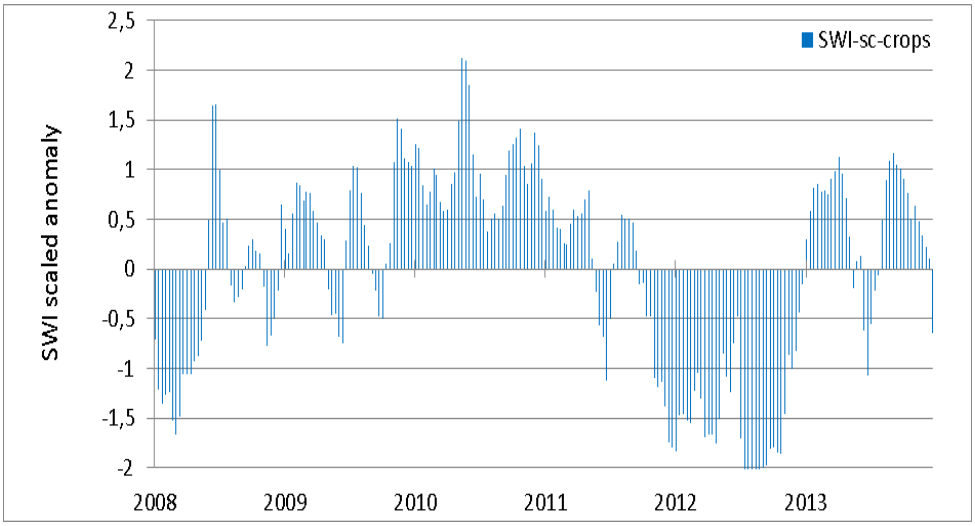

Figure 24: As in Figure 16 for SWI based drought indicator

ANNEX 4: EXAMPLE MAPS OF REGIONAL LDAS-HUNGARY PRODUCTS

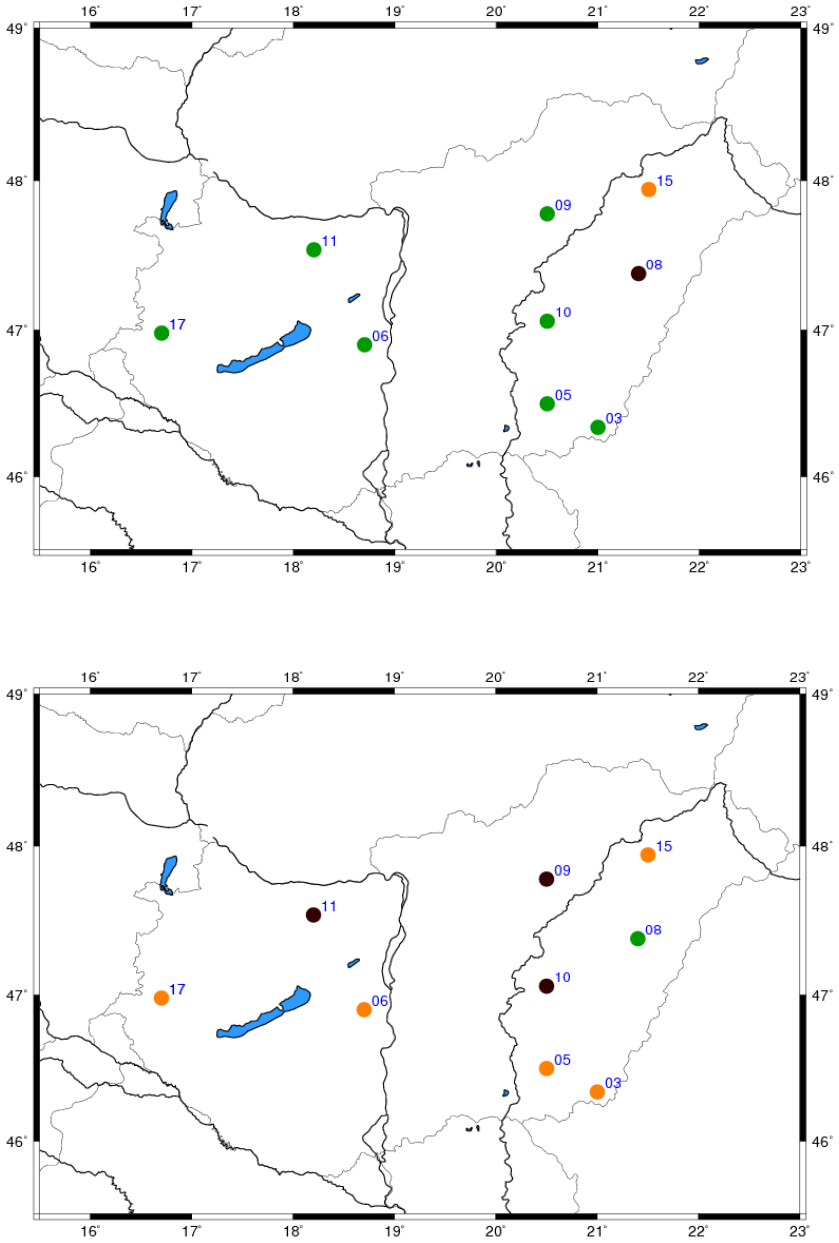

Figure 25: Map of the AGB based drought indicator (DI_{AGB}) for straw cereals over Hungary on 23 May 2013 (top) and on 13 July 2011 (bottom). Green dots are for positive DI_{AGB} values, dark dots for DI_{AGB} values between -1 and 0, orange dots for DI_{AGB} values between -2 and -1.