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Abstract (for dissemination)	In this report, the modeling approach for simulating the biomass, yield, evapotranspiration, CO_2 fluxes and carbon budget of cropland, based on remote sensing products (Land cover maps and LAI maps) will be described and detailed. Last the strategy for validating the model's output will be presented.
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[1] R = Document, report; DEM = Demonstrator, pilot, prototype; DEC = Websites, patent fillings, videos, etc; OTHER; ETHICS = Ethics requirement

[2] PU = Public; CO = Confidential (Consortium and Commission Services); EU-RES = Restreint UE; EU-CON Confidentiel UE; EU-SEC = Secret UE (Commission Decision 2005/444/EC)

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1. Introduction

1.1. Scope of the document

In the emerging Copernicus Earth monitoring era, Europe provides Earth Observation (EO) data from Sentinel-1 (S1) and Sentinel-2 (S2) on a free and open data policy basis. In response of the EO Work programme 'EO-3-2016: Evaluation of Copernicus Services', **Sentinels Synergy for Agriculture** (**SENSAGRI)** aims to exploit the unprecedented capacity of S1 and S2 to develop **an innovative portfolio of prototypes agricultural monitoring services**. When used alone either optical or radar sensors allow the mapping of crop types. However more robust, accurate, frequently updated and comprehensive crop maps are expected from the seldom exploited synergy of both types of measurements. The same holds when dealing with crop modelling. Previous studies have demonstrated that fusion of optical and radar data opens up prospects for enhanced crop modelling capabilities (Revill et al., 2013).

In this document, we present a modelling approach that combines: i) high spatial and temporal resolutions (HSTR) remote sensing data, ii) a simple crop model named SAFY-CO2 (Veloso, 2014) and iii) a strategy to collect in-situ measurements for models' calibration and validation. The combined use of these three 'tools', summarized in Figure 1, opens new perspectives for advanced agro-ecosystems modelling and monitoring at regional or global scales. This document will mainly focus on presenting the model (principle, equations and calibration procedure).

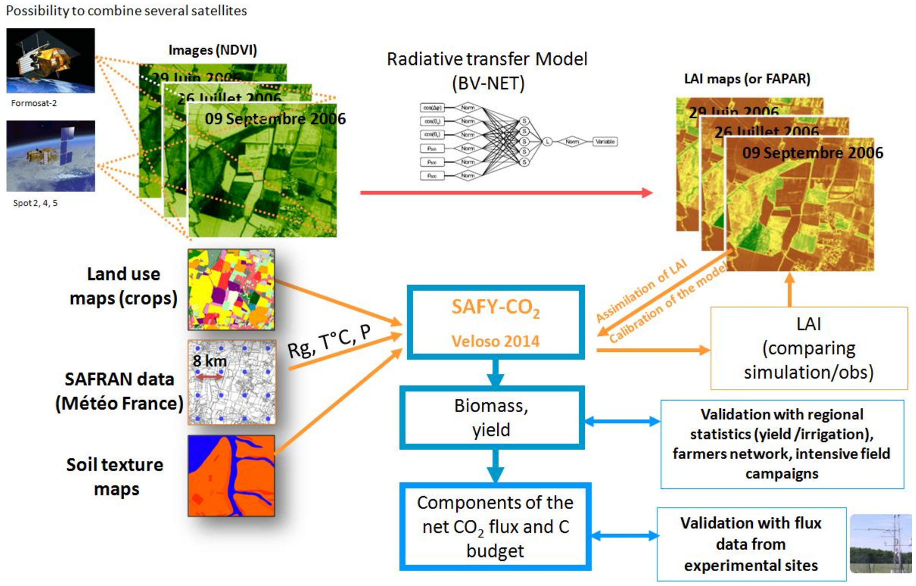

Figure 1. SAFY-CO2 model diagram illustrating the main inputs of the model and the assimilation of series remotely sensed LAI maps for calibrating the model parameters for estimating biomass and yield products but as well the other components of the C budget.

As cover crop maps and LAI maps based on Sentinel 1 & 2 are not available at this stage of the project, we used remote sensing data from the Formosat-2 and SPOT satellites to produce over the French site:

- 1) crop maps that are used to fix crop specific parameters as input in the model and,

-2) leaf area index (LAI) dynamic maps based on the inversion of a radiative transfer model using artificial neural networks (BV-NET tool; Baret et al., 2007).

The dynamic LAI maps are used for calibrating the phonological parameter of the SAFY-CO2 crop models. This semi-empirical model, based on Monteith's light-use efficiency theory and adapted for remote sensing coupling, is calibrated and evaluated in terms of LAI, biomass, yield estimates, photosynthesis (GPP for Gross Primary Production), autotrophic respiration (R_a), heterotrophic respiration (R_h), net CO_2 flux (NEE) and carbon budget (NECB for Net Ecosystem Carbon Budget). The SAFY-CO2 model will later be coupled with a water budget module, based on the FAO-56 method. The final SAFYE-CO2 model will therefore able to estimate as well the components of the crop water cycle, principally evapotranspiration and soil water content. At last, it will be possible to compute water use efficiency (WUE) indices that allow evaluating the crops (locally or regionally), in terms of environmental and agronomical WUEs.

1.2. Notations, abbreviations and acronyms

Some notations, abbreviations and acronyms are listed here below but the parameters and variables (and associated units) used by the model are listed in Table 1.

CESBIO	Centre d'Etudes Spatiales de la BIOsphère
DAM	Dry Aboveground Biomass
ELUE	Effective Light Use Efficiency
EO	Earth Observation
GIS	Geographical Information Software
GPP	Gross Primary Production
HSTR	High Spatial and Temporal Resolutions
LAI	Leaf Area Index
NEE	Net Ecosystem Exchange
NEP	Net Ecosystem Production
NECB	Net Ecosystem Carbon Budget
NPP	Net Primary Production
PAR	Photosynthetic Active Radiation
Ra	Autotrophic Respiration
Rh	Heterotrophic Respiration
RUE	Radiation Use Efficiency
SAFY	Simple Algorithm For Yield estimates
SAFY-CO2	Simple Algorithm For Yield and CO_2 flux estimates
SMT	SuM of Temperature
VPD	Vapor Pressure Deficit
WUE	Water Use Efficiency

Table 1. List of the SAFY-CO2 crop model parameters, notation, units, values or range and the methods of calibration for the winter wheat crop.

	Description	Notation	Units	Value/Range	Method	Model
GPP	Climatic efficiency	ε_c	-	0.48	Literature	SAFY
	Light-interception coefficient	K_{ext}	-	0.76	In situ data	SAFY
	Minimal temperature for growth	T_{min}	°C	0	Literature	SAFY
	Optimal temperature for growth	T_{opt}	°C	20	Literature	SAFY
	Maximal temperature for growth	T_{max}	°C	37	Literature	SAFY
	Polynomial degree	B	-	2	Literature	SAFY
	Corrective factor over GPP during senescence	C_S	-	1.2	In situ data	SAFY-CO$_2$
	Effective light-use efficiency	ELUE	gC.MJ^{-1}	3.7	Calibration	SAFY-CO$_2$
	Correction of the ELUE function (*fELUE*): parameter *a*	*A*	-	0.28	In situ data	SAFY-CO$_2$
	Correction of the ELUE function (*fELUE*): parameter *b*	*B*	-	1.54	In situ data	SAFY-CO$_2$
Ra	Maintenance respiration parameter: Q_{10}	Q_{10}	-	2	In situ data	SAFY-CO$_2$
	Maintenance respiration parameter: R_{10}	R_{10}	gC$_{resp}$ / gC$_{tissus\ viv.}$	0.0025	In situ data	SAFY-CO$_2$
	Growth respiration conversion efficiency parameter	Y_G	-	0.74	Literature	SAFY-CO$_2$
NPP	Root fraction parameter: fr_0	fr_0	°Cd	0.63	Literature	SAFY-CO$_2$
	Root fraction parameter: fr_∞	fr_∞	°Cd	0.11	Literature	SAFY-CO$_2$
	Root fraction parameter: *c*	*C*	-	1.48	Literature	SAFY-CO$_2$
	Carbon content coefficient	C_{veg}	gC / g$_{veg}$	0.46	Literature	SAFY-CO$_2$
Yield	Harvest Index	HI	-	0.45	In situ data	SAFY
	Straw export coefficient	*Sc*	-	0.29[LAM2007] 0.31[LAM2009]	In situ data	SAFY-CO$_2$
Rh	Heterotrophic respiration parameter: Rh_{ref}	Rh_{ref}	gC.m^{-2}.day^{-1}	0.34	In situ data	SAFY-CO$_2$
	Heterotrophic respiration parameter: Q_{10}	Q_{10}	-	2.3	In situ data	SAFY-CO$_2$
	Conversion factor of Ta into Ts	*T*	-	1.07	In situ data	SAFY-CO$_2$
Phenological Parameters	Specific leaf area	SLA	m^2.g^{-1}	[0.0154-0.286]	Calibration	SAFY
	Partition-to-leaf function: parameter a	P_{La}	-	[0.01-0.5]	Calibration	SAFY
	Partition-to-leaf function: parameter b	P_{Lb}	-	[0.0001-0.02]	Calibration	SAFY
	Sum of temperature for senescence	STT	°C	[200-2000]	Calibration	SAFY
	Rate of senescence	Rs	°C. day^{-1}	[10^3-$2x10^4$]	Calibration	SAFY
	Day of plant emergence	D_0	day	-	Calibration	SAFY

2. Model description

The SAFY-CO2 model was developed from the original SAFY (Simple Algorithm For Yield estimates, Claverie et al., 2012; Duchemin et al., 2008) crop model to simulate the components of the cropland carbon budgets. SAFY is a daily time step crop model that simulates the LAI time series, Dry Aboveground Biomass (DAM) and grain yield. SAFY is driven by daily incoming global radiation (Rg) and the cumulated daily mean air temperature (Ta). This approach is based on Monteith and Moss's (1977) light-use efficiency theory, which links the production of the total DAM with the photosynthetically active portion of solar radiation (PAR) absorbed by the plants. In SAFY, the ratio of photosynthesis (GPP) / autotrophic respiration (Ra) is assumed constant when estimating the DAM from the absorbed Photosynthetic Active Radiation (PAR which is estimated directly from the Rg). In SAFY-CO2, the GPP is first estimated as a function of the absorbed PAR. Next, the other components of the net CO2 fluxes and carbon budget are calculated (such as heterotrophic and autotrophic respiration, DAM, yield, etc.). Therefore, because the GPP and Ra are both simulated, the GPP/Ra ratio is not constant. Consequently, variable climatic and environmental conditions can be properly accounted for through crop development. This difference between SAFY and SAFY-CO2 implies that the effective light-use efficiency (ELUE, see Eq. (4)) has different meanings in both models. The following sub-sections present the SAFY-CO2 formalisms for estimating the components of the net CO_2 fluxes and the carbon budget itself. In the following equations, the variables that are calculated for the current day are associated with the index "i", and the variables estimated for the previous day are associated with the index "i-1". All of the parameters and variables (and associated units) used by the model are listed in Table 1.

This model was originally coded in Matlab but to fulfil the objectives of the SENSAGRI project and for being able to run the model on large EO domains, the model will be re-coded in Python, the code will be optimised and coupled with the Geographical Information Software (GIS) platform at CESBIO. The model that has been validated for winter wheat (SAFY has been also validated for summer crops) will also be validated for summer crops over the French site first. Then the model will be tested over the study sites in Spain, Italy and Poland, which are representative of the European crop diversity. In order to refine the specifications of the products (model outputs) and to iteratively assess the services, actors of the agricultural sector will be involved using a Living Lab approach. The combination of user-centred approach and of state-of-the-art algorithms will establish a sound foundation for deciding of a new Copernicus land service.

2.1. GPP estimates

In the SAFY-CO2 model, the GPP [Eq. (1)] is a function of the incoming global radiation (Rg), the fraction of radiation absorbed by the photosynthetically active elements of plants (fAPAR) [Eq.(2)], the climatic efficiency (εc) (which is the ratio of incoming photosynthetically active radiation to global radiation), the effective efficiency of the conversion of absorbed radiation to fixed CO_2 through plant photosynthesis (ELUE) [Eq.(4)] and the temperature stress function (FT). This formalism is similar to that presented by Duchemin et al. (2008) for estimating DAM.

$$GPP_i = Rg_i \times \varepsilon_c \times fAPAR_i \times F_T(Ta_i) \times fELUE_i \times sR10_i \tag{1}$$

$$fAPAR_i = 1 - e^{-k_{ext} \times GAI_{i-1}} \tag{2}$$

$$sR10_i = \begin{cases} 1 & \text{, from emergence until the beginning of senescence} \\ \dfrac{LAI_{i-1}}{LAI_{\max} \times Cs} & \text{, from the beginning of senescence to the end of senescence} \end{cases} \tag{3}$$

$$fELUE_i = \left(a \times e^{R_{df\,i} / R_{g_i} \times b}\right) \times ELUE \tag{4}$$

To account for the fraction of green plant tissues remaining during the senescent phase, a multiplicative coefficient (sR10, Béziat et al., 2009) was added to this formalism to estimate the GPP [Eq. (1)]. The sR10 coefficient is set to 1 from the day of emergence (D0) until the day when senescence begins. From this day until the end of the simulation, sR10 is the quotient between the LAI value of the current day and the maximum seasonal LAI value multiplied by a corrective factor, Cs [Eq.(3)]. At first, the senescence phase acts on the lower portions of the plant (closer to the soil) and on the higher canopy elements. Thus, the actual phenological senescence may be more accentuated than that detected by the satellite observations, which would require a corrective factor. Therefore, the Cs coefficient was included in the computation of sR10 to correct for the effects of senescence over the simulated fluxes.

The effects of the diffuse global radiation fraction over canopy photosynthesis are not usually considered in crop models when estimating crop productivity. However, measurements, including some realised at our sites, have indicated that the efficiency of canopy gas exchange is very sensitive to the diffuse components of incoming solar radiation (Béziat et al., 2009; Hollinger et al. 1998; Roderick et al., 2001). Indeed, when the fraction of diffuse global radiation increases, the proportion of shaded leaves within the canopy decreases. Furthermore, because the photosynthetic rate of leaves is usually saturated at high incoming radiation, the leaves with low irradiance will be more efficient, and reductions in the volume of shade leaves within the canopy indicate that the canopy will be more efficient in the presence of low and diffuse irradiance (Roderick et al., 2001). Thus, it is expected that the photosynthetic efficiency should increase as the fraction of diffuse global radiation increases. Models that ignore the diffuse components of solar radiation are likely to incorrectly simulate GPP dynamics (de Pury & Farquhar, 1997; Roderick et al., 2001). Consequently, our approach is to replace the constant ELUE parameter by considering a function based on the daily fraction of diffuse and global incoming radiation (Rdf/Rg).

Because diffuse incoming global radiation (Rdf) is not often measured on the field and global incoming radiation (Rg) data are, we used the De Jong (1980) approach to estimate the Rdf/Rg ratio over our study area from available Rg. Nevertheless, Rdf/Rg data can also be derived from some global products such as the ERA INTERIM dataset, but at coarser resolutions. Once the fraction of diffuse radiation was calculated (Rdf/Rg), we established a relationship linking it with the radiation use efficiency (RUE). The RUE was defined as the ratio of GPP to Rg. Based upon our field data, we established an exponential function between the Rdf/Rg ratio and the RUE with two fitted parameters, a and b (see (Eq. 4)). In addition to the effects of Rdf/Rg, the photosynthesis process could also be affected by other climatic variables, such as temperature and the water vapor pressure deficit (VPD). For example, low VPD values could correspond with low temperatures that reduce plant respiration and with high diffuse-to-total radiation ratios, which enhance carbon fixation at the canopy scale (Alton et al., 2007; Béziat et al., 2009; Moureaux et al., 2006). Because temperature is already considered when estimating the GPP (see Eq.(2)), we analyzed the relationships between the daily VPD and RUE and between the VPD and diffuse ratio Rdf/Rg. This analysis allowed us to make the methodological decision of considering the effects of the diffuse fraction on GPP estimates but not the effects of the VPD. Indeed, we observed that the VPD values were linearly (and negatively) correlated with the Rdf/Rg (R^2=0.55) and that no significant correlation (R^2=0.00029) was found between the VPD and the GPP residuals (the difference between the observed GPP and the estimated GPP values).

2.2. NPP and Ra estimates

The NPP (for Net Primary Production), representing the amount of biomass produced, is defined as the GPP minus the autotrophic respiration (Ra) [Eq.(5)]. To estimate Ra, we used an approach that separates the Ra into two components, maintenance respiration (R_m) and growth respiration (R_g) (McCree, 1974) [Eq.(6)]. R_m was calculated from the NPP of the previous day and a maintenance coefficient, m_R [Eq.(7)]. The coefficient m_R corresponds to the fraction of maintenance respiration per NPP unit. Because m_R responds strongly to temperature (Amthor, 2000), it was estimated by using a "Q10 type" equation [Eq.(8)]. In this equation, R_{10} is the reference respiration at 10°C.

The Rg was calculated using the method described by Amthor (1989) and improved by Choudhury (2000), as shown in Eq. (9). The constant Y_G is the growth conversion efficiency.

$$NPP_i = GPP_i - R_{a_i} \tag{5}$$

$$R_{a_i} = R_{m_i} + R_{g_i} \tag{6}$$

$$R_{m_i} = NPP_{i-1} \times m_{R_i} \times sR10_i \tag{7}$$

$$m_{R_i} = R_{10} \times Q_{10}^{\left(\frac{T_{a_i}-10}{10}\right)} \tag{8}$$

$$R_{g_i} = (1-Y_G) \times (GPP_i - R_{m_i}) \tag{9}$$

Finally, the total NPP was divided into root (NPP_r) and aerial (NPP_a) components. To estimate NPP, we used a root-to-shoot ratio (RtS) that was calculated according to the methods proposed by Baret et al.

(1992) [Eqs. (10), (11)]. The NPP_a was deduced from the NPP and NPP_r [Eq.(12)] and was used to estimate aboveground biomass production.

$$NPP_{r_i} = NPP_i \times RtS_i \tag{10}$$

$$RtS_i = fr = fr_\infty + (fr_0 - fr_\infty)e^{-c\cdot\left(\frac{SMT_1^i - SMT_1^{D0}}{SMT_1^{Ds} - SMT_1^{D0}}\right)} \tag{11}$$

where SMT is the sum of temperature; D_0 is the emergence date; and D_s is the first day of senescence.

The root fraction (fr) is expressed as the number of growth degree days (°Cd) since emergence; fr_0 is the extrapolated fr value at emergence; fr_∞ is the asymptotic value of fr; and c is the relative rate of decrease.

$$NPP_{a_i} = NPP_i - NPP_{r_i} \tag{12}$$

2.3. LAI, DAM and Yield estimates

The DAM was estimated by dividing the NPPa by the coefficient Cveg, which represents the plant carbon content [Eq.(13)]. Next, the daily aboveground biomass production was converted into the LAI according to the SAFY equations (see Duchemin et al., 2008).

The grain yield estimation [Eq.(14)] depends on the total biomass production (at the end of the vegetative period) and on a constant harvest index (HI).

In some cases, the straw can be exported at harvest. From the perspective of regional scale applications, this term (strawexp) was estimated as a function of the total straw biomass (strawtotal), which corresponds with the final aboveground biomass (DAM_{max}) minus the final grain yield, and the sc parameter [Eq.(22)], which was estimated from in situ data.

$$DAM_i = \frac{NPP_{a_i}}{C_{veg}} \tag{13}$$

$$Yield = DAM_{max} \times HI \tag{14}$$

2.4. NEE, Rh, Reco and NECB estimates

The NEE was calculated as the difference between the NPP and the carbon losses due to heterotrophic respiration (R_h) [Eq.(15)].

$$NEE_i = NPP_i - Rh_i \tag{15}$$

$$Rh_i = Rh_{ref} \times e^{b \times T_{S\,i}} \tag{26}$$

$$Q_{10} = e^{b \times 10} \tag{37}$$

R_h was calculated using an empirical exponential equation that depends on soil temperature (T_s) and on two parameters (R_{href} and b) [Eq.(16)]. The first parameter corresponds to the 'reference R_h' and the second parameter is linked with the Q_{10} constant [Eq.(17)]. The soil temperature (T_s) was calculated from the air temperature (T_a) by multiplying the T_a by a slope factor (t) because a linear relationship was observed between these two variables at our study sites (see Veloso, 2014).

The ecosystem respiration (R_{eco}) is defined as the sum of R_a and R_h [Eq. (18)]. Table 1 summarizes the new parameters of the SAFY-CO2 model in addition to those that were already present in the original SAFY model.

$$R_{eco} = R_a + Rh \tag{18}$$

To compute the annual carbon budget (NECB), carbon import (C_{inp}) and export (C_{exp}) terms were added to the annual cumulated net CO_2 exchange (NEE) between the plot and the atmosphere (NEP, for Net Ecosystem Production) [Eq.(19)]. The carbon input term (C_{inp}) corresponds to the amount of carbon brought to the plot by the seeds at sowing and by the organic fertilizers. The amounts of organic fertilizer (OF) spread at our experimental sites were given by the farmer and converted to carbon equivalents after performing a carbon content analysis. The carbon export term (C_{exp}) corresponds to the amount of carbon exported from the plot at harvest. It corresponds either to the final grain yield [Eq.(20)] or it must be computed from the grain yield and the exported straw [Eqs.(21) and (22)]. The NEP is usually computed from October 1st to September 30th because this period usually corresponds with an agricultural year.

$$NECB = NEP + C_{inp} + C_{\exp} \tag{19}$$

$$C_{\exp} = Yield \quad \text{if only grain is exported;} \tag{20}$$

$$C_{\exp} = Yield + (DAM_{\max} - Yield) \times sc \quad \text{if grain + straw is exported;} \tag{21}$$

$$sc = \frac{straw_{\exp}}{straw_{total}} = \frac{straw_{\exp}}{DAM_{\max} - Yield} \tag{22}$$

The difference between the net carbon inputs (here corresponding to the sum of NEP and C_{inp}) and the carbon loss at harvest (C_{exp}) reflects the short-term evolution of the soil organic carbon content. The micrometeorological convention is adopted, with a negative NEP when the ecosystem is fixing carbon and a positive NEP when the ecosystem is losing carbon. The C_{exp} term is considered as an instant release of carbon to the atmosphere and is positive. The C_{inp} term is a carbon input into the field and has therefore a negative sign. Finally, the annual NECB indicates if the ecosystem is a carbon sink (NECB negative) or a carbon source (NECB positive).

2.5. Model parameterization and calibration

The parameters of the SAFY-CO2 model can be divided into the following three main classes according to the method by which they are set: i) based on literature review, ii) based on in situ measurements and iii) optimized using time series of the remotely-sensed LAI. The parameters included in the two first classes are set as equal for all of the investigated fields and years of study. The parameters in the third category include the ELUE and the phenological parameters. These parameters are set using an iterative method. The ELUE is optimized and set to the same value for all years and fields. The phenological parameters are field-specific and are optimized individually for each winter wheat field and each year by minimizing the error between the simulated LAI time series and those derived from the remote sensing data.

2.5.1. Parameters from the literature review

This group includes the following parameters: the climatic efficiency (ε_C), the specific values of air temperature related to plant functioning (T_{min}, T_{max} and T_{opt}), the polynomial degree (β) of the temperature-stress-function FT, and the growth respiration conversion efficiency parameter (Y_G). Climatic efficiency (ε_C) is considered constant in space and time and is fixed at 0.48 (Varlet- Grancher et al., 1982). The values of air temperature related to plant functioning (T_{min}, T_{max} and T_{opt}) were set according to the standard parameters of the STICS model (See Brisson et al., 1998; http://www.avignon.inra.fr/agrocilm_stics/). Thus the minimal, optimal and maximal temperatures for winter wheat growth were set to 0, 20 and 37°C, respectively; the polynomial degree (β) of the temperature-stress-function FT was set as described by Duchemin et al. (2008); and the constant Y_G was fixed at 0.74, which is the average of three values for winter wheat given by Amthor (1989).

2.5.2. Parameters from in situ data

This group includes the light-interception coefficient (K_{ext}), the harvest index (HI), the corrective factor over the GPP during senescence (C_s), the straw export coefficient (sc), the root fraction parameters (fr_0, fr_∞ and c), the carbon content coefficient (C_{veg}), the maintenance respiration parameters (Q_{10} and R_{10}), the heterotrophic respiration parameters (Rh_{ref} and Q_{10}), the conversion factor of T_a into T_s (t) and the parameters related to the fELUE function (a and b).

These parameters are fixed exclusively based on in our Auradé and Lamasquère situ measurements (Béziat et al., 2009) without regard for the SAFY-CO2 model. The K_{ext} was computed by inverting Beer's law and by using the fractions of absorbed photosynthetically active radiation (FAPAR) and LAI, which were both obtained from hemispherical photographs taken over wheat crops (at different growth stages). A value of K_{ext}=0.76 was found (Veloso, 2014). The HI was fixed by plotting the destructive biomass against yield measurements (performed over 16 fields over the French study area; see Veloso, 2014). A HI equal to 0.45±0.05 was obtained, and the corrective factor C_s was empirically fixed at 1.2. The sc parameter was estimated according to Eq.(22) from the in situ grain yield, total aboveground biomass and exported straw biomass data at the Lamasquère site.

The root fraction related parameters were initially set according to Baret's results (fr_0=0.6, fr_∞=0.1 and c=1.5) and were slightly modified as described by (Béziat, 2009) to better fit with our study sites according to the measurements performed at the experimental sites. The parameters were fixed to fr0=0.63, fr_∞=0.11 and c=1.48 and the C_{veg} coefficient was set to 0.46 gC/g_{veg}, (Béziat, 2009). According to Béziat (2009), the Q_{10} coefficient is approximately 2, and the R_{10} parameter was set to 0.0025 gC released per gC of living plant biomass. The Rh_{ref} parameter in Eq. (17) was calibrated using the NEE data from our Auradé and Lamasquère flux towers from 2006 to 2010 over bare soil periods. The Q_{10} parameter was held constant at 2.3 (equivalent to b=0.0833) and a calibration value of 0.34 gC.m^{-2}.day^{-1} was found for Rh_{ref} (Delogu, 2013).

Analyses of the air and soil surface temperature data measured by our meteorological towers at the experimental sites throughout the year (including vegetative and bare soil periods) from 2006 until 2010 indicated a linear correlation (R^2 = 0.92) with a slope of 1.07, which was used to estimate T_s from T_a (Veloso, 2014). To estimate parameters a and b for the effective light-use efficiency function (fELUE, Eq. (4)), field data from the radiation sensors mounted on our experimental sites were used. The relationships between RUE and Rdf/Rg were defined as an exponential function, with parameters a=0.28 and b=1.53 and a determination coefficient of R^2=0.61 (Veloso, 2014).

2.5.3. Parameters calibrated from remote sensing data

The third class of parameters includes the parameters that were calibrated using an iterative method based on minimizing the Root Mean Square Error (RMSE) between the remotely sensed BV-NET LAI time series and the time series estimated by the SAFY-CO2 model.

These parameters include the ELUE and the phenological parameters, the plant emergence day (D_0), the specific leaf area (SLA), the two parameters of the partition-to-leave function (P_{La} and P_{Lb}), and the two parameters of the senescence function (sum of temperature for senescence (STT) and rate of senescence (Rs)). The minimization procedure was based on an adapted version of the Nelder-Mead simplex method (Lagarias et al., 1998), which can be used to constrain the range of the parameter values to find solutions within realistic intervals. This adapted version runs the optimization process 30 times, with different starting points for each of the parameters to avoid obtaining a local minimum solution, and then retains the set of parameters that provides the best solution (smaller RMSE).

The first step of the iterative calibration process consists of simultaneously optimizing the seven parameters (ELUE, P_{La}, P_{Lb}, STT, Rs, D_0, and SLA) for each field. The intervals of the possible solutions for each of these parameters are summarized in Table 1 (for more details see Veloso, 2014). Next, the phenological parameters remained constant and only the ELUE parameter remained free. At our site, an optimal value for ELUE of 3.7gC.MJ-1 was found for winter wheat and used for all of the studied fields and years based on the hypothesis that this parameter remains constant. In SAFY-CO2, the ELUE corresponds to the efficiency of the photosynthetically active radiation absorbed by the canopy (APAR) being converted to fix some CO_2 by plant photosynthesis. For this study, the ELUE could be set as constant because variable climatic and environmental effects were accounted for by other terms for estimating the GPP [Eq.(1)] and because we assume that the LAI dynamics integrate the different stresses that the vegetation may experience during the growing season. The last step of calibration consisted of re-optimizing the six phenological parameters for each field individually and for each year. Finally, the calibration procedure was completely based on the satellite-derived LAI time series. Therefore, no in situ data concerning the net CO_2 fluxes or biomass/yield were used in this step.

3. Model validation

Validation of the simulated CO_2 fluxes (GPP, ecosystem respiration (Reco), NEE) will be performed against eddy-covariance flux measurements (Aubinet et al., 1999; Baldocchi, 2003) that were carried out since 2005 over the Auradé and Lamasquère flux sites (Béziat, 2009) included in the French study area. They are both part of the ICOS ERIC network (https://www.icos-cp.eu/) for measuring ecosystem's greenhouse gases emissions. The EdiRe software (Robert Clement, c 1999, University of Edinburgh, UK) was used to calculate fluxes. Flux filtering, quality controls, gap filling, NEE partitioning into gross primary production (GPP) and ecosystem respiration (Reco) components were performed following the CarboEurope- IP recommendations (Beziat et al., 2009). At Auradé, the crop rotation is winter wheat-sunflower-winter wheat-rapeseed, the plot is not irrigated, only grain is exported and only mineral fertilisers are applied. At Lamasquère, the crop rotation is winter wheat-maize for silage, the plot is irrigated when maize is grown, both grain and straw are exported and both organic and mineral fertilizers are applied (for a complete description of the sites see Béziat et al., 2009).

Crop production (biomass and final grain yield) will be evaluated against in situ measurements (from the two flux sites and from samples collected during field campaigns). Détails concerning protocols of biomass sampling and yield estimates during the SENSAGRI field campaign are listed in SENSAGRI deliverable D7.3. Protocols concerning collection of ground truth for LAI, biomass and yield validation over the French site during previous years are described in Veloso (2014).

Apart from the four core European test sites (France, Spain, Italy and Poland) the model shall be tested against ground-truth data coming from agricultural sites outside Europe. In this respect, the

SENSAGRI consortium partners' Pan-European and global dissemination network will be utilized for obtaining access to agricultural sites across the world, e.g. as part of the JECAM network (http://www.jecam.org/) which gather 34 sites located in all the continents or as part of the ICOS and FLUXNET networks gathering experimental plots equipped with eddy-covariance flux stations.

Three of the partners of SENSAGRI manage a JECAM site, namely in France, Italy and Spain. In addition, UPS-CESBIO and its foreign partners manage two JECAM sites located in Morocco and Tunisia. We plan to test SENSAGRI over one or both of these North-African sites (SENSAGRI D2.1, 2017).

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