A SURFACE ALBEDO PRODUCT AT HIGH SPATIAL RESOLUTION FROM A COMBINATION OF SENTINEL-2 AND SENTINEL-3 DATA: TEMPORAL MONITORING OF AGRICULTURAL ALBEDO AND CARBON FLUXES

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Abstract : As an addition to carbon stocking, grasslands could also provide an additional leverage against climate change : reduction of radiative forcing though increases in surface albedo. Sentinel-2 satellites offer a global coverage of Earth surface with a high spatial resolution (between 10 and 60 meters for a pixel) and an image frequency of 5 days on average. Sentinel-3 satellites offer images at a lower spatial resolution (300 meter pixels) but at a higher frequency (almost daily images). Combining Sentinel-2 and Sentinel-3 images allows us to produce a high resolution albedo product with sufficient temporal resolution to track monthly changes on agricultural fields over the year. This is the preliminary step to the study of albedo as an attenuation factor for climate change, reducing radiative forcing on exploited grasslands. First results calculated since the beginning of the 2020 summer are presented with comparisons with ground data gathered over a French prairie.

Key words: Sentinel-2, Sentinel-3, Albedo, Grassland, Carbon

Résumé : En plus du stockage de carbone, les prairies pourraient également fournir un levier d'atténuation supplémentaire contre le changement climatique : la réduction du forçage radiatif par l'augmentation de l'albédo de surface. Les satellites Sentinel-2 offrent une couverture globale de la surface terrestre avec une haute résolution spatiale (entre 10 et 60 mètres pour un pixel) et un temps de revisite de 5 jours en moyenne. Les satellites Sentinel-3 offrent des images à une résolution spatiale plus faible (pixels de 300 mètres) mais à une fréquence plus élevée (images quasi quotidiennes). La combinaison des images Sentinel-2 et Sentinel-3 nous permet de fournir un produit albédo à haute résolution avec une résolution temporelle suffisante pour suivre les changements mensuels sur les champs agricoles au cours de l'année. Il s'agit de l'étape préliminaire à l'étude de l'albédo comme facteur d'atténuation du changement climatique, réduisant le forçage radiatif sur les prairies exploitées. Les premiers résultats calculés depuis le début de l'été 2020 sont présentés avec des comparaisons avec des données sol recueillies sur une prairie française.

Mots-Clés : Sentinel-2, Sentinel-3, Albedo, Prairie, Carbone

Introduction

Ruminant livestock contributes to climate change (CC) through its enteric methane emissions, which are partly offset by the use of grasslands as a carbon (C) storage factor (70 t C/ha). The ALBEDO project proposes, in addition to the well-known mitigation levers of CC, which are the reduction of greenhouse gas emissions (GHG) and carbon storage, to study a third innovative abatement: albedo. This power to reflect solar radiation by grasslands helps mitigate climate change. The primary objective of this study is to better characterize the spatio-temporal variability of grassland albedo in France. For this purpose, measurements are carried out on experimental farms (Figure 1) and by high-resolution optical satellite, for different grassland management and pedoclimatic situations. The aim is to identify and quantify the abatement for increasing albedo in order to mitigate CC, from the plot to the territory scale, using remote sensing analyses performed by the Sentinel 2 and Sentinel-3 satellites. This project aims to strengthen the arguments in favor of sustainable grassland farming based on optimal use of grasslands.

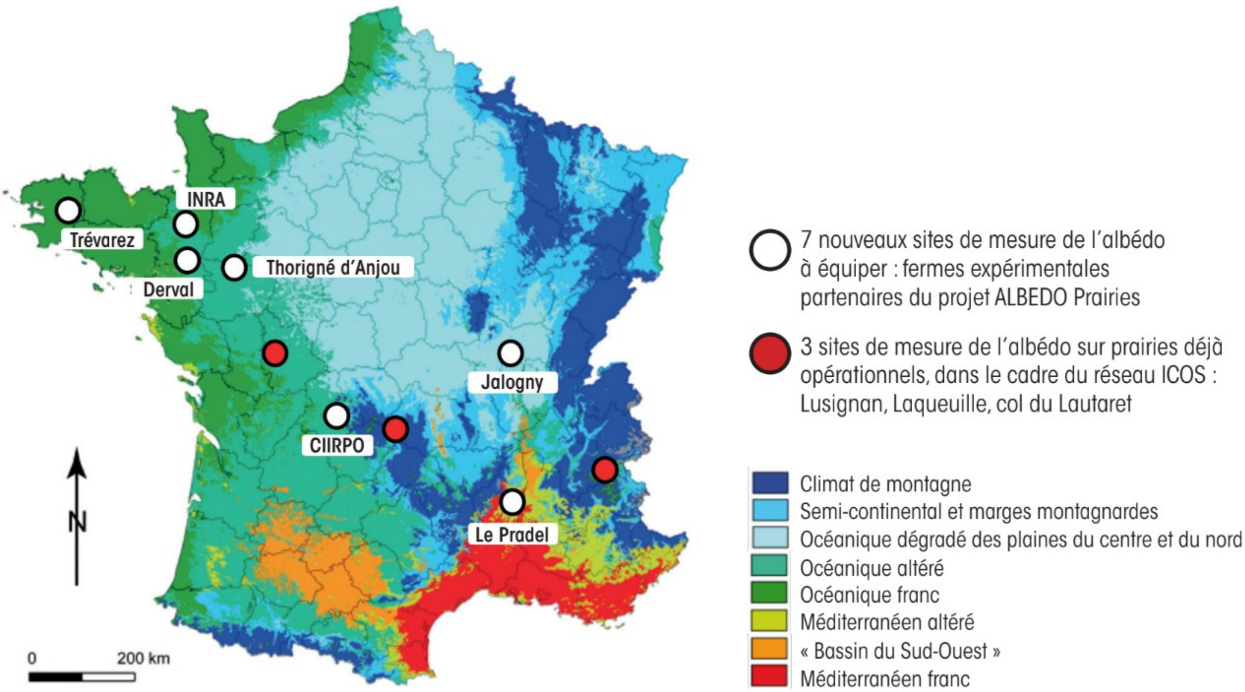

figure 1 – Map of the studied grasslands

Luyssaert et al (2015) have shown that changes in practices have as much impact on variables describing surface conditions (albedo, surface temperature, etc.) as changes in land use. It is therefore necessary to better characterize the determinants of surface albedo variations in temperate grasslands as it has been done for example for field crops.

The advent of satellite fleet like the satellites Sentinel-2 (A & B) and Sentinel-3 (A & B) fosters the environmental research to enter into a new era owing to both an appropriate revisit - typically 5 days - of the whole globe at an enhanced time and high spatial resolution (HR). High quality pre-processing of Sentinel-2 radiometry supports the dissemination of scenes finely calibrated and corrected from atmospheric effects. Though less popular than Sentinel-2, Sentinel-3 offers a frequent revisit - almost daily - but a moderate spatial resolution. The routine distribution of Sentinel products supports many applications, notably in agriculture, food security, weather forecast, climate change impact studies, water use, forest and natural resources management. A merged reflectance product in a spectral domain covering visible, near infrared and mid-infrared offers a new challenge of collecting cutting-edge information at the benefit of crop monitoring. The outcomes of the dissemination of quality-checked HR product will certainly benefit programs like GEOGLAM (Group of Earth Observation for Global Agricultural Monitoring) for which main concerns are the onset and decay of crops, and early warning. The presentation will highlight the operational methodology to be implemented in order to perform a measurement of the HR surface albedo and also ensure a trimmed monitoring of the worldwide crops.

1. SURFACE ALBEDO PRODUCT

The surface albedo is an Essential Climate Variable (ECV) that needs to be generated on a regular basis in order to ensure continuous estimates of the net radiation and besides the water and carbon balance. Among the key issues, are a timely production, the availability of historical archives, and consistency of the long-term archive. First of all, the removal of atmospheric effects must be properly handled. For Sentinel-2, cloud removal and aerosol correction rely on the MAJA method proved to be efficient for processing multi-temporal and multi-spectral data sets [2]. For Sentinel-3, freely distributed by VITO (Vlaamse Instelling voor Technologisch Onderzoek) for the present study, less effort was performed regarding the atmospheric correction, in particular the removal of aerosol effects. On the other hand, the wide field-of-view (FOV) of Sentinel-3 allows to sample the Bidirectional Reflectance Distribution Function (BRDF, figure 2).

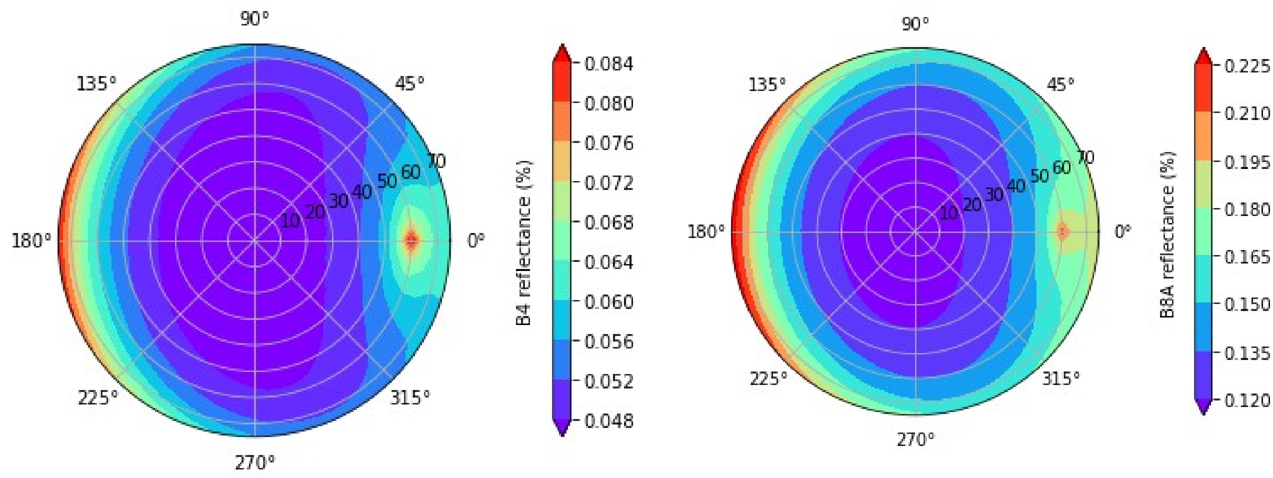

figure 2 – BRDF PROSAIL simulations Band B4 (red, left) and B8A (near infrared, right)

Herein, the surface albedo was first calculated using Sentinel-2 data. The choices were a 60-days synthesis period and a 10-days composite period in order to ensure that sufficient observations were available to inverse a BRDF model and thereby estimate the surface albedo. Capturing surface albedo variations along the season is meaningful for most agricultural practices. Since the aim is also to make the method fast and operational, computation time is accounted for and codes were optimized to run with a single core of the CNES' HAL supercomputer. The method – to turn operational - makes use of the well-established approach based on a semi-empirical BRDF kernel-driven (Equation 1) [3]. Given the scarcity of cloudless Sentinel-2 observations (on average 50% of images are cloudy in France, but that can go up to 70% in certain regions), adding Sentinel-3 information (beyond 150 clear images per year on average for France) was necessary to collect enough observations and get a timeliness and reliable albedo product.

Equation 1: [illegible] (1)

In addition, Sentinel-3 has a wider range of viewing angles compared to Sentinel-2 (less than ±15° for Sentinel-2 viewing zenith angle, compared to ±55° for Sentinel-3), which allows to better constrain the inversion of a BRDF model. Figure 3 shows the BRDF simulated with the PROSAIL model (combined PROSPECT leaf optical properties model and SAIL canopy bidirectional reflectance model [4]) for Sentinel-2 bands B4 (red) and B8A (near infrared). It can be seen that the availability of data for viewing zenith angles less than 15° for Sentinel-2 cannot provide a mean estimate of the reflectance and thereby albedo. This outlines clearly the added-value of Sentinel-3, which view zenith angles can be up to 55° and more. In addition, the increased number of clear images allowed for a reduction of synthesis and composit period to 30 and 5 days respectively. To prepare the BRDF model inversion, Sentinel-3 tiles at 300 meters resolution were resampled to 10 meter on the Sentinel-2 grid using a nearest-neighbor interpolation scheme.

Broadband albedo products were derived using narrow to broadband conversion coefficients based on numerical experiments using the PROSAIL radiation transfer model. BRDF coefficients can also serve to perform a normalization of the data. In order to best answer users' requirements, the surface albedo products are delivered with a quality flag and an uncertainty assessment. Also the true age of the product is indicated as being the median value of the clear sky scenes used during the composite period. The methodology displayed in Figure 3 is similar to a methodology recently developed for PROBA-V sensor to obtain a 300 meter surface albedo product in the frame of the Copernicus Global Land Service. BRDF parameters are used to calculate black sky (Directional Hemispherical Reflectance, DHR) and white sky (Bidirectional Hemispherical Reflectance, BHR) albedo, which is converted to blue sky albedo with the diffuse (α) component estimated from MAJA aerosols (Equation 2).

Equation 2: [illegible] (2)

The first step of the albedo product validation use ground measurements gathered on the 6 grasslands in France (Figure 1). These grasslands are equipped with weather stations founded by the French institute for livestock (Institut de l'Elevage) as part of a study regarding the characterization of the albedo of French grasslands and the impact of specific agricultural practices on albedo and carbon stock. On each station, standard meteorological variables (temperature, wind speed and direction, precipitation, Figure 4) are collected from meteorological towers also equipped with pyranometers CNR4 measuring downward and upward shortwave radiation.

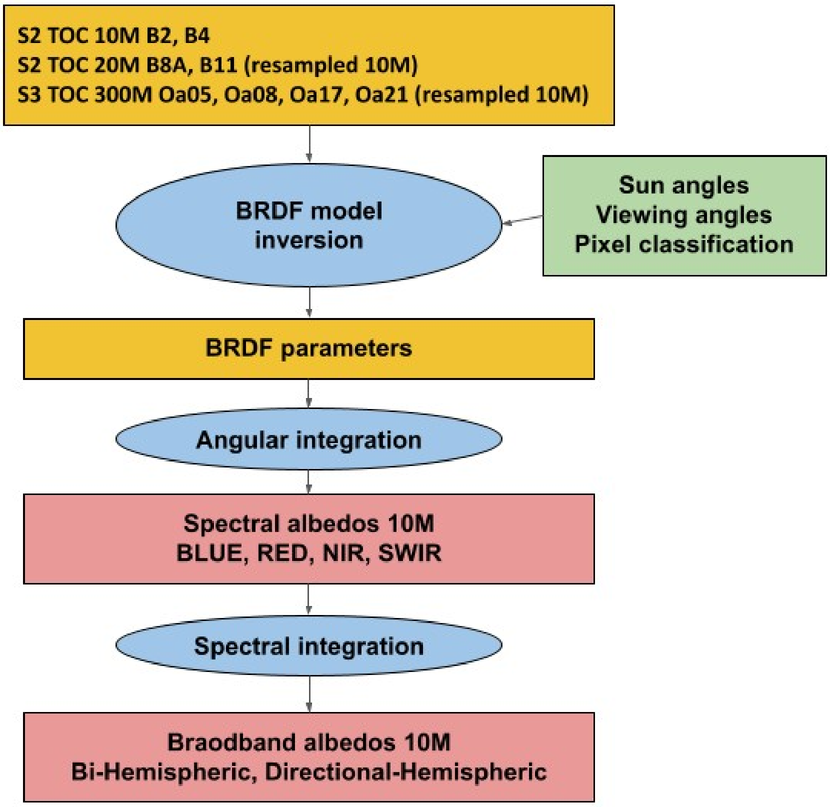

figure 3 – Albedo processing chain flow-chart. In the first cell are the different S2 and S3 bands used and their resolution. TOC : Top Of Canopy, NIR : Near InfraRed, SWIR : Short Wave InfraRed, BRDF parameters : Equation 1

Figure 4 – Measurement towers

The result of albedo calculation with Sentinel-2 and Sentinel-3 data over a grassland located at Pradel, France (31TFK Sentinel-2 tile) can be seen in Figure 5. It is compared with ground measurements. Albedo is measured every 10 minutes at the station. The measurements shown in figure one are for solar noon. The calculated albedo is the DHR component (Directional Hemispherical reflectance also called black-sky albedo) which is an integration of the bi-directional reflectance over the viewing hemisphere. Note that a BHR (Bi-Hemispherical Reflectance also called white sky albedo) product is also an output of the albedo processing chain.

Here are a few points we can observe on Figure 5:

- There is a high dispersion of the albedo measurements, especially during winter (2020-2021). This is probably due to low and varying illumination conditions and changes of the canopy wetness.
- The albedo calculated from satellite data is lower than the ground measurements. This may be due to a low signal value coming from Sentinel-2 data.
- We can clearly observe a link between the NDVI (Normalized Difference Vegetation Index) estimates and weather conditions: there is a trend of rising NDVI values after precipitation episodes, and reduction of NDVI values during dry episodes (like the 2020 summer). NDVI changes can also be linked to specific agricultural practices like mowing (in June 2020 and September 2021, before dry periods).

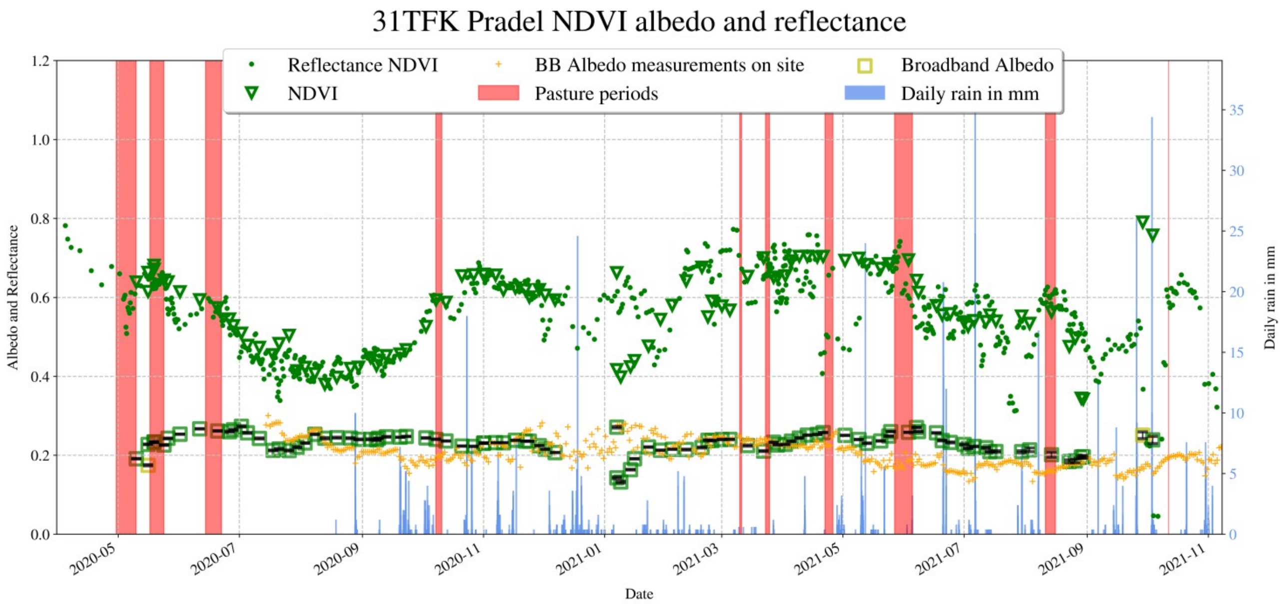

figure 5 - Broadband Albedo squares are colored according to the quality of the estimation, green is a high quality, yellow is an average quality and red (excluded from the current graph) are bad quality. Both S2 and S3 images are used for this time series.

The actual albedo product will be improved in different ways:

- The filtering is today too severe for the input data, which arbitrarily consists in discarding some input data and leads to having more gaps in albedo products time series.
- MAJA products for Sentinel-2 include an aerosol optical tickness (AOT) from which it is possible to derive a diffuse fraction, which is not actually the case for Sentinel-3. Giving a weight between DHR and BHR to get a blue-sky albedo will lead to improvement in wintertime when the sun is low above the horizon. Besides, it should act as a noise reduction.

- Gap-filling and consistency will enhance the reliability of the surface albedo product from implementing a recurrent method previously considered in the frame of the Copernicus Global Land Service.

2. SUMMARY AND FUTURE PROSPECTS

A processing chain has been developed to provide a global and accurate estimate of the surface albedo at a high spatial resolution and appropriate timescale. The method could be applied worldwide and treat any kind of target. Herein, the focus was carried on the monitoring of grasslands. Combining Sentinel-2 and Sentinel-3 satellites improve the temporal shape of the surface albedo time series to capture fine agricultural practices or meteorological events on a given target.

Specific attention will be carried on the validation of the surface albedo product in considering the 6 stations measuring the surface albedo set up as part of the Institut de l'Elevage study over grasslands dedicated to livestock. In fine, the goal is to convert quantitative estimates of the surface albedo into radiative forcing terms and then in CO_2 fluxes equivalent in order to demonstrate the role of grasslands for a sustainable agriculture and as an abatement of global warming.

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