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USING COVER CROPS AS A MITIGATING LEVER AGAINST GLOBAL WARMING

Férvier – juillet 2020

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ABSTRACT

Today the societies face an unprecedented challenge trying to restrain the global warming. After the COP21 that took place in Paris in 2015, the signatory countries of the United Nations Framework Convention on Climate Change (UNFCCC) agreed on the limitation of greenhouse gases emissions allowing to limit the temperature increase under 1.5°C compared to the pre-industrial era. Yet, the scientific community believe that consideration should be given to the use of geo-engineering to keep global warming below the defined threshold. In this context, a recent CESBIO and CNRM-led study has shown that land cover management could be used as a mitigating lever against global warming. They demonstrated that the introduction of cover crops over the Europe could result in a cooling effect. Indeed, in most parts of Europe the albedo of vegetation is higher than the albedo of bare soil so in these areas, the introduction of cover crops over fallow periods leads to a negative radiative forcing proportional to the increase in albedo. Based on the use of remote sensing data, land cover databases, meteorological data, national agricultural statistics and ground measurements the authors established a cover crop introduction model that simulate the radiative forcing followed by the increase in albedo. Carrer & al (2018) showed that, according to a realistic scenario, cover crops could be introduced over 4.17% of the European surface resulting in a radiative forcing of 3.16MtCO2-eq.yr^{-1}.

Here we propose a deeper analysis of what climatic impact could be induced by the use of cover crops. Considering that cover crops are buried into the soil, the following increase in soil organic matter leads to the darkening of the ground which will affect the surface albedo and thus the radiative forcing. This effect is considered here. We also brought in a new implementation scenario of introduction to simulate all cases currently set up *i.e.*, after a winter crop and before a summer crop but also between two summer crops and to get a more realistic estimation of the albedo effect. Also we refined our results by filtering the area covered by snow during cover crops implementation. So far we used snow-free satellite albedo data leading, as shown by Kaye and Quemada (2017) to wrong estimation of radiative forcing over areas and periods covered by snow.

1. INTRODUCTION

Since the beginning of the industrial era (defined as 1850-1900 period in the IPCC 2013) atmospheric carbon dioxide concentration is continuously rising, increasing global temperature. An ambitious objective of the 2015 United Nations Climate Change Conference (COP21) was to contain the global air temperature increase below 1.5°C by the end of the 21st century. But current climate projections indicate that this limit is likely to be exceeded without strong mitigation strategies. In the fifth assessment report of the IPCC (IPCC, 2013), the Representative Concentration Pathways (RCPs) predict that the global mean temperature increase is likely to be 0.3-1.7°C for the most optimist scenario (RCP2.6) while the scenario considering the highest GHG emissions (RCP8.5) predicts an increase of 2.6-4.8°C compared to the average temperature over the period 1986-2005. As this period is already 0.63°C warmer than the pre-industrial era (IPCC 2013), it is very unlikely that the stated objective of the COP21 will be achieved without the use of geoengineering techniques. Even if GHG emissions stopped, global temperature will continue to increase during decades due to ocean and carbon cycle inertia (Matthews and Caldeira, 2008).

'Geoengineering', also called 'climate engineering', refers to "a broad set of methods and technologies that aim to deliberately alter the climate system in order to alleviate the impacts of climate change" (IPCC 2014). Those methods can be divided into two categories: the carbon dioxide removal (CDR) and the solar radiation management (SRM) techniques. SRM approaches aim at increasing the fraction of solar radiation reflected back to space by increasing Earth's albedo. Among SRM approaches, some are interested in increasing the atmosphere albedo through seeding clouds to increase cloud droplet numbers and thus cloud albedo (Latham et al., 2008) or by injecting sulphated aerosols into the atmosphere (Crutzen, 2006; Robock et al., 2009). Others take an interest in increasing the land surface albedo. Akbari et al., (2012) and Jacobson and Ten Hoeve, (2012) investigate the climatic impact of making rooftops white worldwide while Ridgwell et al., (2009) quantified the cooling effect of increasing cropland leaf albedo. CDR approaches are intended to remove carbon from the atmosphere to reduce the greenhouse effect. To do so, those techniques either increase natural C sinks through ocean fertilisation or afforestation/reforestation (Caldeira et al., 2013) or try to capture it directly through different methods.

The recent 4 per 1000 initiative (Chabbi et al., 2017) aims at using cropland as a lever against global warming through CDR. The objective is to increase global soil organic carbon (SOC) stocks by 4‰ per year in order to counteract the anthropogenic GHG emissions. They identified

Cover Crops (CC) as the most efficient management practices to sequester carbon in the soils. A CC is a vegetative cover (*e.g.,* clover, phacelia, etc.) introduced between two cash crops allowing to keep the soil covered. The CC can be used as a source of energy but are usually incorporated into the soil enabling to increase SOC stocks. This practice can thus be considered as CDR effective but it is also SRM efficient in our area of study. Indeed, in most parts of Europe, vegetation albedo is higher than the bare soil albedo (Campbell and Norman, 1998; Carrer et al., 2014) so the introduction of CC over fallow periods leads to a negative Radiative Forcing (RF) that we try to assess in the present study.

This radiative forcing has already been assessed by Kaye and Quemada, (2017). They estimate the climatic impact of the CC by considering all aspect involves (i.e. carbon sequestration, N_2O fluxes, etc.) and they suggest that the CC albedo effect could induce a RF equivalent to 12 - 46 $gCO_2.m^{-2}.yr^{-1}$. Nevertheless, as other studies they used a constant atmospheric transmittance while it's known to vary temporally and spatially. Sieber et al., (2019) highlighted the importance of considering those variations because it could lead to wrong RF estimates and even resulting in warming instead of a cooling effect. Later Carrer et al., (2018) estimated that the RF induced by the cropland albedo increase following the introduction of CC would be equivalent to 16 $gCO_2.m^{-2}.yr^{-1}$ (consistent with Kaye and Quemada, (2017)), considering a spatially and temporally variable atmospheric transmittance. Nevertheless, in their studies, Carrer et al., (2018) only consider the introduction of CC after a winter crop and before a summer crop while this agronomic practice is also set up on other crop rotations. Also, the albedo products used in their studies were snow-free leading to an overestimation of the radiative forcing over areas covered by snow. So more recently Lugato et al., (2020) overpassed those issues by simulating CC introduction at European scale coupling remote sensing information with soil survey datasets and a biogeochemical model. They showed that, considering snow cover, the radiative mitigation potential of CC would be between -7 and 12 $gCO_2.m^{-2}.yr^{-1}$. Highlighting the importance of considering the snow cover to allow to determine areas of potential introduction. Yet, most of studies trying to assess the climatic impact of CC consider that the CC are buried into the soil. This incorporation increases soil organic matter which in turn darkened the soil. Yet, most of the studies (all listed above) do not consider any changes in bare soil albedo while it has already been proven that it could have strong radiative impact (Meyer et al., (2012)).

In the present study we went further in the assessment of the CC's climatic impact induced by the change in surface albedo linked to the introduction of CC, considering the darkening of the soil induced by the increase of soil organic matter as well as additional scenarii (compared to

Carrer et al., 2018) based on agronomic observations.

The objectives of this study are to i) improve our knowledge about CC climatic impact by considering phenomena that could have strong impacts and that has not been considered so far, ii) assess the loss/gain of the radiative mitigation potential according to the length of CC introduction, and other agricultural practices (i.e., mulching), iii) know if CC could be used as a strong climate mitigation practises.

In a first part of the study, the data and the model are presented. Then the new implemented scenario as well as a filter and soil albedo degrowth simulations are discussed. The associated results are then introduced. The study ends by a discussion about the incertitude and the feedback that should be taken into account to impart our study.

2. MATERIALS & METHODS

2.1. Data

2.1.1. Albedo products

Assessing radiative forcing induced by CC requires to estimate an albedo gain. To do so, data on the bare soil and vegetation albedo are needed. Usually, there are two ways of estimating the surface albedo from satellite measurements, the direct estimation methods and the physically based estimation methods. The direct estimation methods aim at deduced a broadband albedo directly from top-of-atmosphere (TOA) reflectances based on a large database representative of cover types and atmospheric condition diversity. The physically based estimation methods are more complex and require different steps: the TOA reflectances are converted into surface directional reflectances which is then converted into spectral albedos before being converted into broadband albedos. The MODerate Resolution Imaging Spectroradiometer (MODIS) Bidirectional Reflectance Distribution Function (BRDF)/albedo algorithm is based on these later methods (Schaaf et al., 2002). But the current spatial resolution (500 m) of these products is not sufficient to meet the objectives of simulating CC introduction. To address this issue, Carrer et al., (2014) retrieved a bare soil (α_{BS}) and vegetation (α_{VEG}) albedo from MODIS products, using a Kalman-Filter method, and the ECOCLIMAP classification (see section 2.1.2). This led to a global albedo mapping at a temporal resolution of 8-day over the period 2001-2010.

In order to get the total albedo of a given pixel, data on vegetation index are required. This index indicates the fraction of soil occupied by the vegetation and allows to estimate the total albedo of a given pixel (see 2.2.3).

Then, to obtain albedo products (bare soil and vegetation albedo) over a period of 50 years, the temporal series 2001-2010 have been replicated 5 times. The under study goal is to assess the influence of the decrease of the bare soil albedo. Therefore, all other parameters are considered conserved over a period of 50 years.

2.1.2. ECOCLIMAP classification

In order to determine the areas and periods of CC introduction the ECOCLIMAP classification (Faroux et al., 2013) was used. This database provides, all over Europe and at a spatial resolution of 1 km, the fraction of C3 and C4 crop as well as the fraction of bare soil. Since the proposed method aims at simulating cover crop introduction between two cash crops (either summer or winter crop) a correction was applied on ECOCLIMAP C3 and C4 crop fractions. Indeed, for the purpose of this approach, crops have to be split according to their crop cycle period (i.e. winter or summer crop) rather than according to their photosynthesis types (C3, C4). A correction factor was thus defined for each country from the fraction of C3 plants in ECOCLIMAP and the fraction of winter crops of 2011 Eurostat data (https://ec.europa.eu/eurostat/fr/web/agriculture/data/database). This correction factor was then applied to each pixel of the associated country.

2.1.3. Climatological Data

Estimating top-of-atmosphere radiative forcing (RFTOA) from a change in surface albedo requires meteorological data of incoming short-wave radiation (SWin) and of atmospheric transmittance (TA). The ERA-5 products Hersbach et al., (2020) was used here. Those data (https://cds.climate.copernicus.eu) are available at global scale at a hourly time step and a spatial resolution of 31km. The TA was estimated as the ratio of the incoming solar radiation at TOA (RTOA) to SWin allowing to describe its spatial and temporal variation. Since the CC development is conditioned, in the proposed approach, by rainfall, ERA-5 data of total precipitation was used. Finally, and in order to filter areas covered by snow, the snow depth was estimated thanks the snow depth (water equivalent) and the snow density as suggest by the era 5 documentation.

$$\text{snow\_cover (SC)} = \min(1, (RW*SD/RSN) / 0.1)$$

Where RW is density of water equal to 1000 and RSN is density of snow (parameter 33.128). ERA5 physical depth of snow where there is snow cover is equal to RW*SD/(RSN*SC). https://confluence.ecmwf.int/display/CKB/ERA5%3A+data+documentation.

2.2. Model

2.2.1. Zone and periods of introduction

To simulate the introduction of CC, the crop rotations, between summer and winter crop, had to be simulated. In Europe, most of the cultivated crops can be split into 2 categories; winter crops (sown in fall and harvested in early summer) and summer crop (sown in spring and harvested in fall). From the ECOCLIMAP derived vegetation indexes of the winter and the summer crops, vegetation indexes corresponding to those four rotations were rebuilt, e.g., winter-winter (R_{WW}), summer-summer (R_{SS}), winter summer (R_{WS}) and summer winter (R_{SW}). Each rotation is characterised by fallow periods where CC can be introduced following a few rules and which are defined from the vegetation indexes. For every pixel of the study area containing a crop fraction, a rotation crop fraction (R_{WW}, R_{SS}, etc.) is defined. These fractions were estimated for from the fraction of winter and summer crops inside the pixel and agronomic expertise allowing to determine the fraction of the main crop type that is rotated with the other one, according to the rule: « only X% of the main crop type is in rotation with the other crop type, the rest being in rotation with the same type of crop (i.e., R_{WW} and/or R_{SS}) ».

The CC’s dynamic

2.2.2. Scenarii of introduction

In their study Carrer et al., (2018) simulated the introduction of CC for a maximum introduction period of 3 months only on rotations R_{WS} which usually correspond to the rotation having the longest fallow simulating a period of 3 years. Following advice from the ‘4p1000 initiative’, here the simulations correspond to a duration of 50 years length CC were also introduced on the R_{WS} and R_{SS} rotations and for longer periods. These introductions must follow undermentioned rules:

- If the sowing date of the crop following the CC occurs before early fall, one month of bare soil is required before the sowing of the following crop inducing an early CC destruction.
- If the sowing date of the crop following the CC occurs after early fall, no fallow period is needed before the next crop so the CC is destroyed when the following crop is sown.
- Albedo of the CC does not exceed 0.95 of the crops (winter or summer) maximum

- The vegetation indexes of the CC could not exceed 0.95 of the maximum vegetation indexes of the indexes where they have been introduced.

The simulation respecting all these rules constitutes the reference scenario (S_{REF}).

From this reference scenario, others have been simulated in order to refine the results and get closer to the real radiative impact that could be achieved by the use of CC.

The second scenario simulated in these study takes into account the water required to the CC development. As suggested by Brisson et al., (2009), we fixed a minimum limit of 30 mm of cumulated rain the month following the introduction of CC. This constitutes the 'rain scenario' R_R.

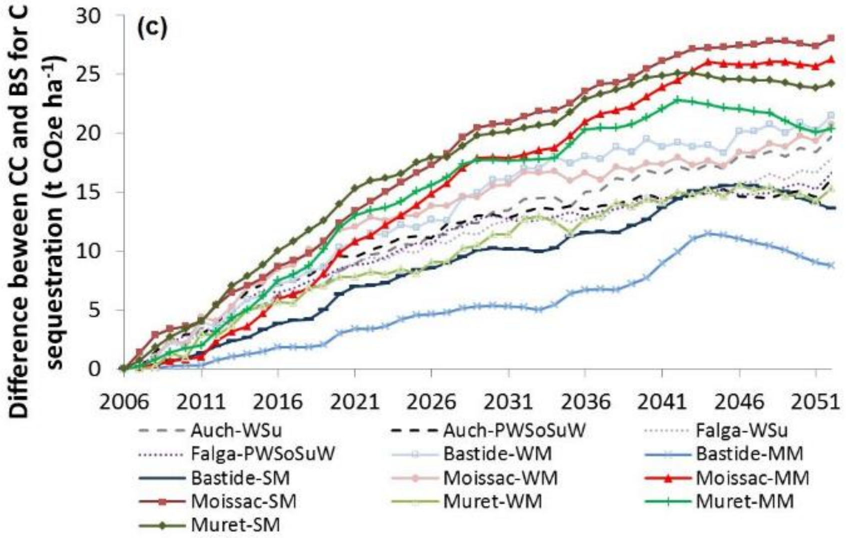
Since we use snow-free albedo products and because Kaye and Quemada, (2017) and more recently Lugato et al., 2020 highlighted the importance of taking into account the snow cover, a third scenario has been simulated considering snow cover besides rainfall. The same assumption as in Lugato et al, (2020) was made here. Between 0 and 21 cm of snow, the albedo of the soil is considered to be the albedo of the snow (0.65) which lead to an albedo decrease if CC are introduced. But if the snow depth exceeds 21 cm, no albedo gain/loss is estimated. This scenario is the R_{R_S} scenario for rain and snow.

In their study Lugato et al., (2020) simulated a brighter mutant cover crop based on the study of Sakowska et al., (2018). We also simulated a scenario with a maximum albedo of 0.29 as proposed in Sakowska corresponding to a chlorophyll deficient soya bean. This scenario will be called $R_{R\_S\_M}$ for mutant CC.

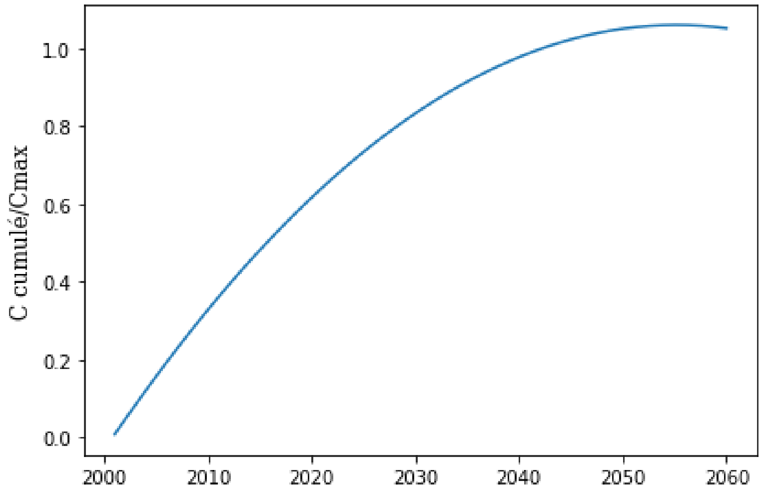
Finally, and as it is explained above, the soil albedo decrease (due to the incorporation of fresh organic matter) seems to be preponderant against other scenarii we thus simulated all above scenarii considering or not the bare soil albedo decrease. When this decrease is considering, the scenario will be underlined (i.e., $\underline{R_R}$, $\underline{R_{R\_S}}$, $\underline{R_{R\_S\_M}}$).

2.2.3. Bare soil albedo decrease

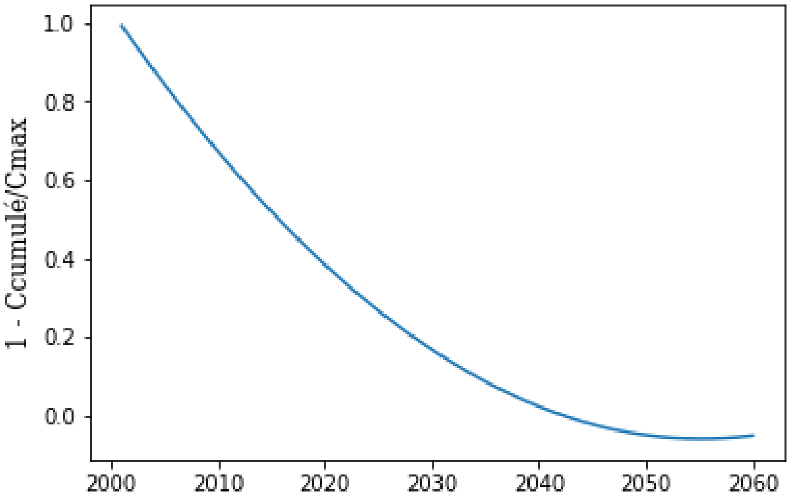
To simulate the decrease in soil albedo several assumptions were made. First, we consider that the albedo of soil is proportional to the organic matter concentration. We thus used results from Tribouillois et al., (2018) to determine the carbon stored in the soil.



Tribouillois & al (2018)



Evolution du carbone cumulé dans les sols agricoles après introduction de couverts intermédiaires Tribouillois & al (2018)



Evolution de l'albédo des sols nus agricoles au cours du temps :f(c(t))

Then it has been necessary to combine f(c(t)) with the initial temporal series of the bare soil albedo. The method is decreased above.

$$alb\text{-}solnu\text{-}model\,(t) = f1\,(c\,(t)) \times alb\text{-}solnu\text{-}pixel\,(t) + f2\,(c\,(t)) - f2\,(c\,(t)) * MEAN\,(alb\text{-}solnu\text{-}pixel(t)) \qquad (1)$$

- alb-solnu-model(t) is the modelled bare soil albedo taking into account the decreasing of the bare soil due to the incorporation of organic matters in bare soil.

- f1 (c (t)) is the function created previously, constrained by the boundary conditions allowing to obtain the desired initial and final albedo amplitude.
  initial amplitude = amplitude (alb-solnu-pixel (t = 0))
  final amplitude = amplitude (alb-solnu-ukraine)
- f2 (c (t)) is obtained thanks to the boundary conditions making it possible to obtain the mean value of final decay (minimum of the Ukrainian bare soil albedo) and the mean value of the start of the decline of the bare soil albedo of each pixel.
  f2 (c (t = 0)) = alb-solnu-pixel (t = 0)
  f2 (c (t = +00)) = alb_solnu_ukraine (t = 2010)
- alb-solnu-pixel (t) is the bare soil albedo of the pixel considered
- alb-solnu-ukraine is the minimum albedo in Ukraine
- f1 (c (t)) * alb-solnu-pixel allows to decrease the amplitude of the albedo over time.
- The addition of f2 (c (t)) - f2 (c (t)) * MEAN (alb-solnu-pixel (t)) makes it possible to fix the evolution of the average value of the bare soil albedo without touching to the signal amplitude.

2.2.4. Radiative forcing calculates

The radiative forcing induced by CC are estimated from the difference in albedo between a baseline scenario (reference) and the estimated albedo.

$$\alpha = \alpha_{VEG} * veg + \alpha_{BS} * (1 - veg)$$

$$\alpha_{CC} = \alpha_{VEG\_CC} * veg\_CC + \alpha_{BS} * (1 - veg\_CC)$$

$$\Delta\alpha = \alpha - \alpha_{CC}$$

Where α_{VEG} is the vegetation albedo, α_{BS} is the bare soil albedo and veg the vegetation index. The model of introduction of CC used in this study allows to estimate a CC vegetation index (veg_CC) as well as a CC albedo (α_{VEG_CC}) from α_{VEG} and veg following a few rules:

- The albedo of the CC cannot be higher than 0.95*max(α_{VEG}).
- The vegetation index of the CC cannot exceed 0.95*max(veg).
- The CC linearly growth during 1.5 months (or 0.75 for Nordic countries *i.e.*, latitude > 57.8°).
- A minimum fallow period of 1 month is needed before next cash crop.

To limit the albedo of CC below the maximum of observed vegetation albedo tends to minimise the radiative mitigation potential. Indeed, if CC are used for the purpose of radiative mitigation effect, species with high albedo could be used as it is proposed in Sakowska et al., (2018) which present a ‘yellow’ soya bean mutant with an albedo of 0.29.

$$RF = SWin*Ta*diff\_alb$$

3. RESULTS

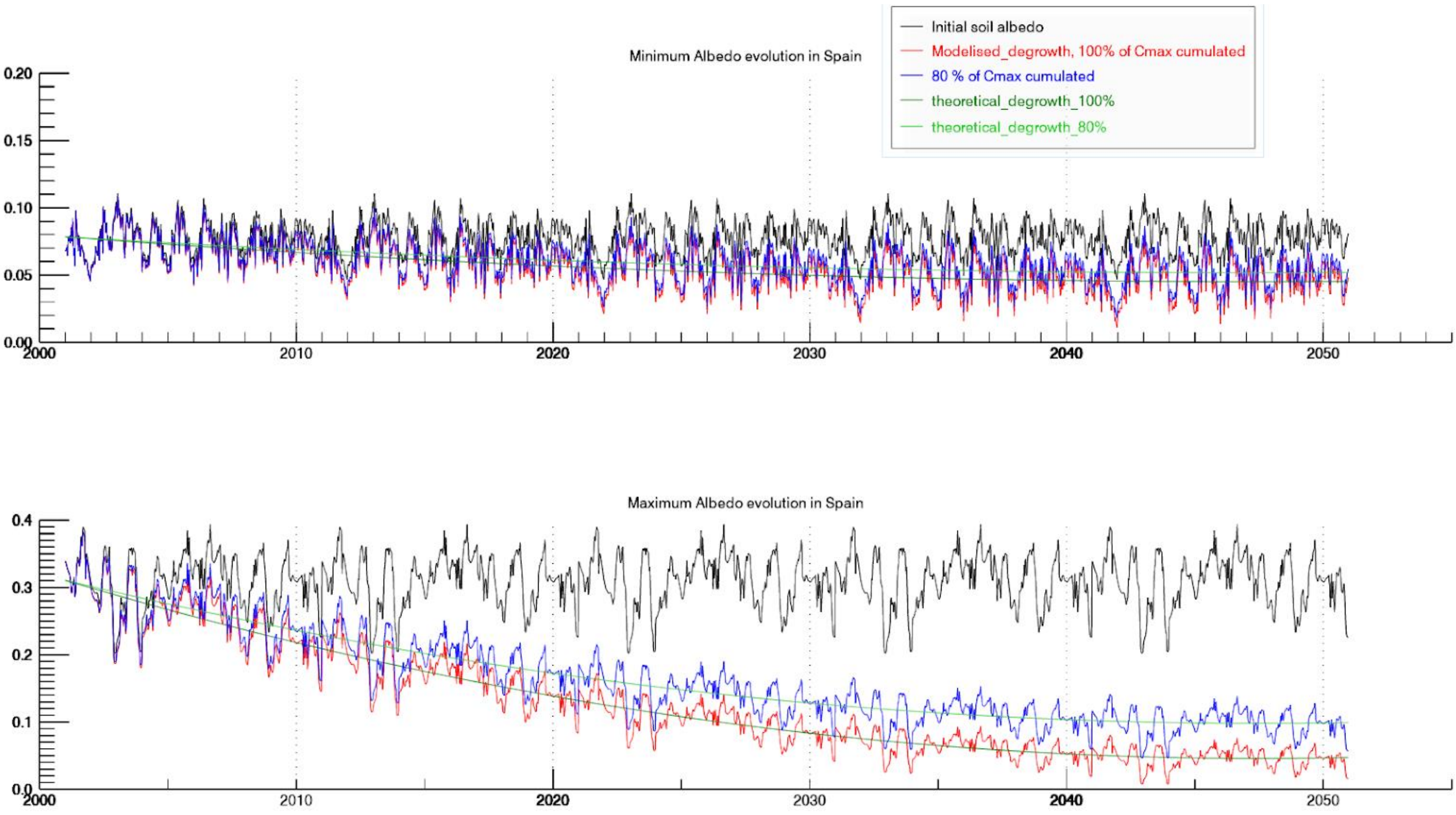
3.1. Modelling of bare soil albedo decrease caused by cover crops

The simulations were implemented in two specific geographic areas per European country. The area corresponding to the place where on average the weakest bare soil albedo has been recorded (Minimum Albedo evolution), and the area where on average the strongest bare soil albedo has been recorded (Maximum Albedo evolution).

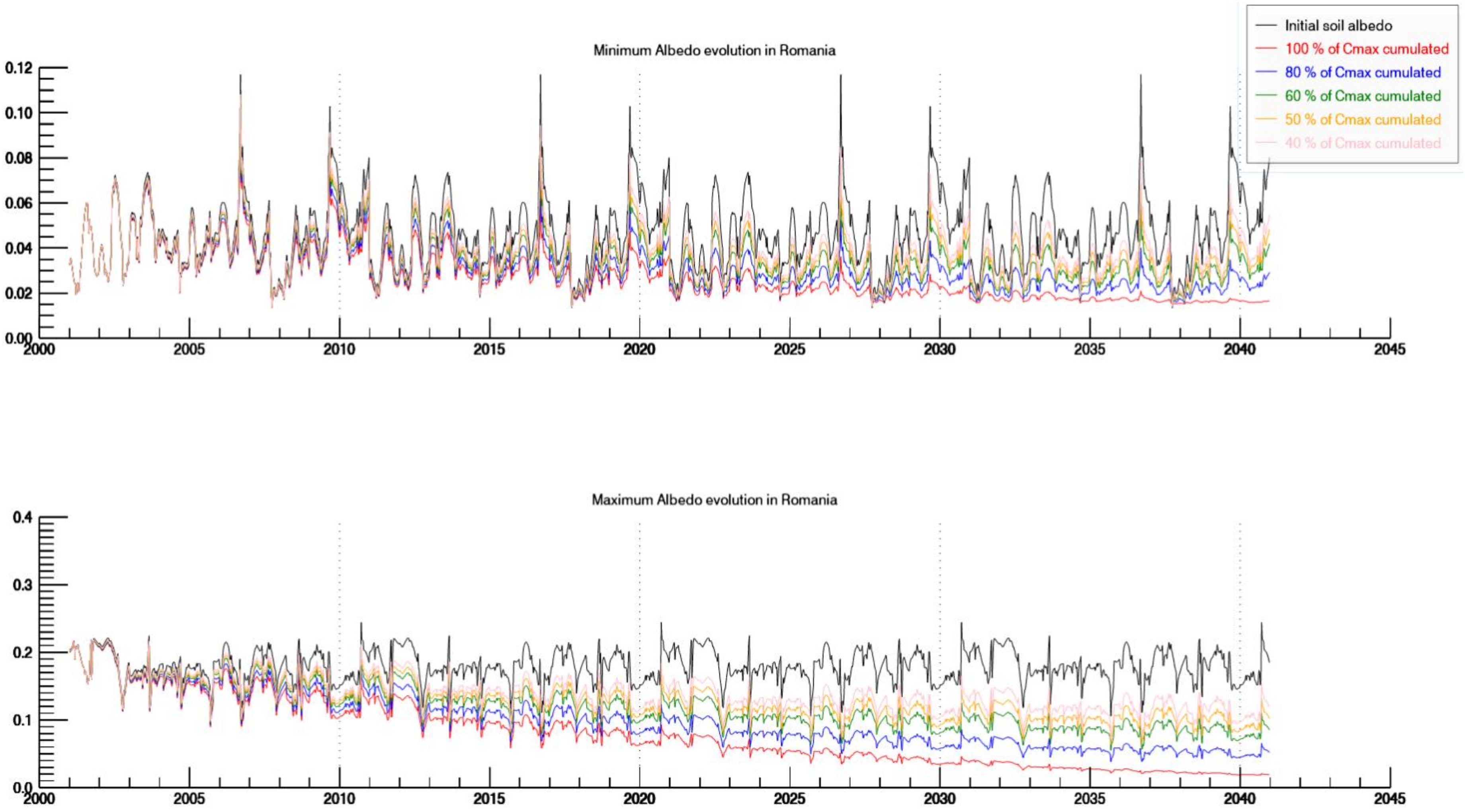
Various albedo decay scenarios have been set up, making it possible to account for the diversity of European soils which will not react in the same way to the incorporation of organic matter. Differents cenarii of degrowth of the dynamic of the albedo will be tested.

100 % of carbon storage corresponds to the case where all the dynamics of bare soil albedo are constrained to decrease (amplitude and mean value) to the reference bare soil albedo.

Assuming, that some south European soils could not reach this reference value, several scenarii of degrowth have been designed (100% in red, 80 % in blue).

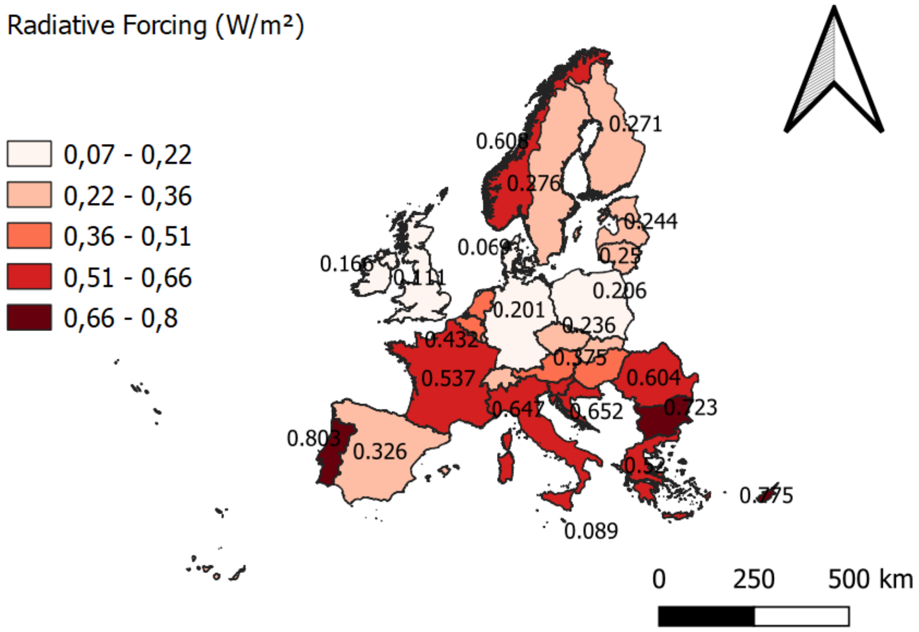


Bare soil albedo dynamics over time in Spain without (black curve) and with (coloured curves) accounting for the soil darkening effect induced by cover crops. Upper figure for the location in Spain where bare soil albedo is lower in 2000. The lowest figure for the area in Spain where bare soil albedo is higher in 2000.

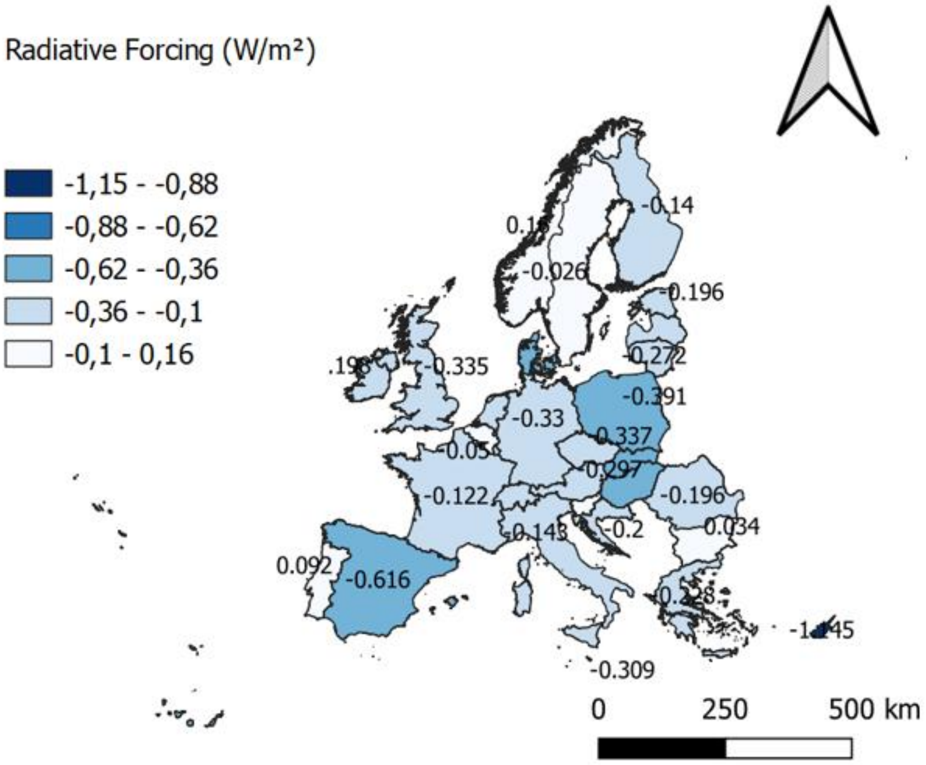


Bare soil albedo dynamics over time in Ukraine without (black curve) and with (coloured curves) accounting for the soil darkening effect induced by cover crops. Upper figure for the location in Ukraine where bare soil albedo is lower in 2000. The lowest figure for the area in Ukraine where bare soil albedo is higher in 2000.

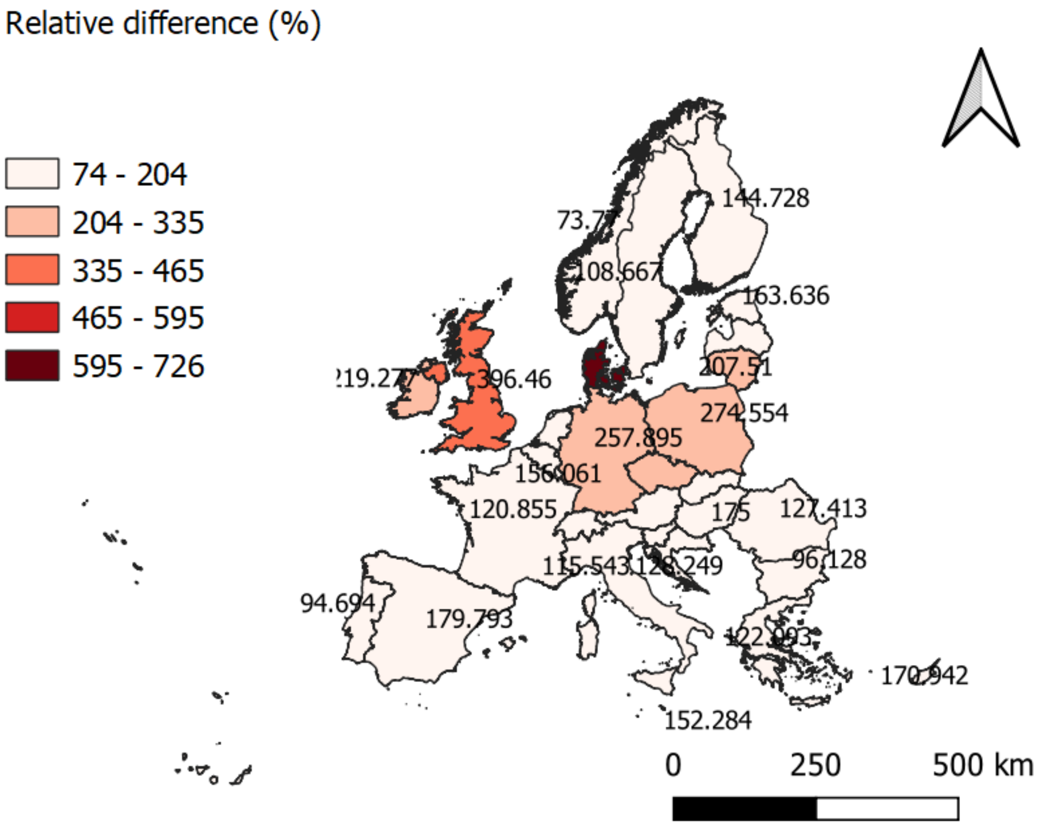
3.2. Impact of bare soil albedo decrease



radiative forcing aggregated by country resulting from the installation of cover crops according to the 4/1000 scenario suggested by INRAE – The bare soil albedo decrease is not taking into account.



radiative forcing aggregated by country resulting from the installation of cover crops according to the 4/1000 scenario suggested by INRAE – The bare soil albedo is taking into account.



Relative difference between radiative forcing taking into account the decrease of bare soil albedo and radiative forcing not taking into account the decrease of bare soil albedo

Taking into account the decrease in bare soil albedo generates the transition from positive radiative forcing (signifying a cooling effect on the climate) to negative radiative forcing (signifying a warming effect on the climate).

Thus, the blackening effect of the soil by the incorporation of organic matter completely counterbalances the beneficial cooling effect identified by Carrer & al (2018).

4. DISCUSSION

4.1. Agronomic benefits

When properly implemented, the benefits of cover corps on ecosystems and soil condition can be significant. The first uses of cover crops by farmers came in response to
soil erosion issues. In fact, the aerial part of the cover crops protects the soil against hydrometeors while the underground part preserves the soil structure by limiting compaction, which is beneficial for the following crop. In addition to limiting soil erosion, cover crops will limit water drainage, the risk of flooding, and reduce fertilizer consumption (Juste et al., 2012). Indeed, cover crops play 2 roles on the fertility of agricultural plots. Directly by fixing atmospheric nitrogen when cover crops legume-like species are sown (green manure). And indirectly by increasing the organic matter content of the soil, which increases its capacity to retain and return water and mineral elements to the plant.

In addition, these effects offset part of the GHG emissions linked to the production of fertilizers for agriculture (Poeplau & Don 2014). Finally, cover crops can be effective in combating pests and the development of weeds.

On the other hand, if the choice of cover crops species is poorly made, the effects can be counterproductive. Cover crops can promote the appearance of pests (e.g. slugs) and in some cases be difficult to destroy which can become problematic for the next crop which will see soil resources decrease. So, if the rains are not sufficient during the development of the cover crops or after their burial, the water that they will have taken from the soil for their growth may be lacking for the proper development of the next crop.

4.2. Climatic Effects

. Finally, for a few years now, a small scientific community has been interested in the cooling effect on the climate, via the albedo effects, which cover crops can represent. For several years now, the CESBIO and CNRM teams have been studying the radiative forcing linked to the albedo effects induced by the introduction of cover crops by trying to model the effects of this agricultural practice as realistically as possible. The under-study work highlights the fact that the blackening effect of the soil by the incorporation of organic matter completely counterbalances the beneficial cooling effect identified by Carrer & al (2018). Thus, the bio physic effect (albedo) could counterbalance the biogeochemical (CO2 capture) one.

4.3. Methods

The modelling of the introduction of cover crops at the European scale presented in this thesis was carried out using satellite products disaggregated at 1/20 °. This spatial resolution obviously leads to uncertainties in the calculations which could in the years to come, reduce considerably with the arrival of very high-resolution albedo products. So, although our results have been validated through comparisons with in-situ data, the modelling uncertainty may be reduced in the near future.

Furthermore, beyond the effect of precipitation on the possible development of cover crops, the model implemented does not take into account climatic phenomena that may limit the development of cover crops such as frost, diseases or even post-drought lifting. Even if some limiting factors (e.g. temperature) can be included in our treatment chain, others (e.g. diseases) are difficult to model. The model put in place for this study will therefore be improved as a result of this work in order to be realistic enough to convince political decision-makers. Uncertainties will also be calculated using equation 9 for the different scenarios. Finally, we have worked with "snow-free" products while in winter a large part of northern / north eastern Europe is covered with snow with a much greater albedo than any type of vegetation. Our results can therefore be refined by taking into account snow-covered surfaces at which the albedo gain generated by the introduction of cover crops will be cancelled since they would be covered by snow, just as bare ground would have been.

4.4. Heat flux

The introduction of cover crops not only has an impact on the radiative balance and the carbon cycle but it will also impact the heat fluxes (sensible, H and latent, LE) therefore the water cycle, the richness of soils and potentially micro-scale meteorological phenomena. Indeed, when we modify the structure and the cover of a soil, its surface fluxes will in turn be modified and will themselves have feedback on other phenomena. The Bowen ratio (H / LE) is used to characterize the heat exchange between the surface and the atmosphere. Davin et al., (2014) showed that maintaining residues at the surface (which also makes it possible to increase albedo compared to bare soil) reduced the rate of evapotranspiration and therefore the Bowen ratio, which would increase surface temperature. However, the cooling effect achieved with the change in albedo would remain dominant in the face of the increase in temperature due to the increase in Bowen's ratio. It will therefore be necessary to take into account the impact of cover crops on these heat flows and may be used as input for coupled surface / atmosphere models in order to study the climate impacts. Current knowledge, in particular that acquired within the framework of M. Ferlicoq's thesis (2015) shows that cover corps increase latent heat fluxes (LE) to the detriment of sensible heat fluxes (H) which would result in increased the cooling effect of cover crops.

Following this thesis, the study will therefore focus on the various points discussed above, which will make it possible to refine the climate change mitigation potential of cover crops.

5. CONCLUSION

The use of cover crops is now widespread in some countries (e.g. Switzerland). Legislation and a European directive encourage this practice for its role as a nitrate trap. A change in agricultural practices could therefore make it possible to transform this sector of activity from a major source of GHGs to a means of combating climate change.

Besides, the long-term stake of this research is to convince policy makers to work against global warming by supporting the introduction of cover crops, including through financial and technical assistance to farmers. Today there is evidence (Woodward et al., 2009) which proves that the emblematic measure of 1.5 ° C (maximum increase in global temperature) before the end of the century, taken during COP21 will be very difficult to achieve. Even while considerably reducing our GHG emissions. This very restrictive post-COP21 limit (which replaces the 2 ° C limit) seems to implicitly lead to the use of geoengineering if we do not review in a more general way the functioning of our thermo-industrial societies. This study proposes an alternative solution to the use of the injection of sulphated aerosols into the stratosphere.

However, we must not lose sight of the fact that any large-scale human intervention will have effects which are not yet well known. Even if today the biophysical effects of cover crops represent only 10% of the total carbon capture effect compared to the biogeochemical effects, this study calls for caution, accounting for the potential warming effect induced by the use of intermediate cutlery.

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COVID-19

Suite à l'épidémie du covid-19, l'essentiel de mon stage s'est effectué en télétravail. Ainsi du retard a été pris dans le 1er mois suivant le confinement, le temps que des solutions informatiques soient mises en place afin de favoriser le télétravail au CESBIO. Comme je travaillais principalement avec le logiciel IDL, payant et que les accès à distance au CESBIO étaient limités par les mesures de sécurités informatiques du CNES, j'ai trouvé le moyen de travailler à distance sur le réseau du LEGOS en empruntant les accès informatiques de Igor Vanpoucke qui a eu la gentillesse de m'autoriser à utiliser son espace de travail informatique. En fin de stage, finalement j'ai eu accès au réseau Météo France par le biais de Dominique Carrer. Ainsi, ayant du changer 3 fois de serveurs au cours du stage (CESBIO, LEGOS, MF), cela a inévitablement occasionné du retard par rapport au travail à accomplir durant le stage. Malgré cela, les objectifs du stage ont tout de même pu être atteints.