CIRCLE 2
CLIMATE IMPACT RESEARCH & RESPONSE COORDINATION FOR A LARGER EUROPE
EU FP7 ERA-NET

“CIRCLE-2 MOUNTain Group”

CAMELEON FINAL Report

Project title
***CA**rbon dynamics in **M**ountain **E**cosystems: analyzing **L**andscape-scale **E**ffects **O**f a**N**thropogenic changes (climate and land-use).*
ACRONYM
CAMELEON

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1. Project summary

The combination of climate and land use changes has triggered important land cover changes in European mountains over the last 50 years. These changes may accelerate with climate change in the 21st century. The linkages between vegetation dynamics and primary productivity of mountain ecosystems and their ability to mitigate carbon emissions are still poorly understood. The purpose of the CAMELEON project is to improve our knowledge of the carbon cycling of mountain ecosystems. key objectives is (i) to understand how land use changes translate into plant functional diversity changes (ii) to model the carbon cycling in mountain ecosystems at the landscape scale using detailed accounts on climate forcing and plant functional diversity (iii) to forecast the potential changes in the carbon stocks and fluxes in mountain ecosystems.

Our project targets three long-term mountain research areas located in Eastern Pyrenees (Spain), South-Western Alps (France) and Eastern Alps (Austria), representing contrasting historical and climatic contexts.

First of all, the project allows us to define a new database of ecological data for the three region of interest. A set of high resolution maps historical land cover change sin 1950 was constructed. Then different land use scenarios for the near future were defined in collaboration with local stakeholders.

A compilation of large ecophysiological data was also compiled including co2 flux measurements, functional traits and botanical releves. This allow us to better understand the biodiversity of the mountains ecosystems over the three sites

The ecological data compiled was used to improve and test the ORCHIDEE terrestrial model over the mountain ecosystems. Comparison with in-situ flux measurement and remote sensing data show that calibrated model reproduce well both observed net carbon fluxes and interannual variation of plant phenology

Then the ORCHIDEE model was used to better understand the change in carbon cycle and the main drivers of these changes. A series of simulations was conducted using regional land use scenario and downscaled climate scenario

The three sites exhibit contrasted responses. For Austria we found a relatively large increase in productivity both for historical period and for the future. This induces an increase of carbon storage, even if the increase of productivity is partly canceled by the increase of soil respiration. On the opposite for Pyrenees, after a productivity increase during the historical period, there is a progressive decrease in the future due to increase of summer drought. This induce a carbon lose after 2050. The French Alps shows an intermediate response with increasing productivity during historical period with stabilization after 2050. Then the soil carbon sink decreases progressively decrease after 2050.

For Stubai, the first driver of productivity increase is the temperature, followed by the CO_2 fertilization effect. For Pyrenees, on the opposite climate has a negative effect mainly driven by the decrease of precipitation. This negative effect is partly compensated by the positive effect of CO_2.

Thanks to the newly developed module for simulating grassland management, ORCHIDEE-GM we was able to estimate the maximum animal density that can be feed by local forage resources and its adaptation to climate and land use change.

For Stubai, the increase of productivity should allow to increase the animal production for more than 30%. However this climate effect should be counterbalanced by projected land use change that results in a decrease of intensive (cut) grassland. For Alynia, the increasing drought in the future should decrease to potential of animal production. For Vercors the system is more complex as animal are only In Vercors during summer whereas they are in Crau plain during winter. Like for Pyrenees, the Crau should experience an increase of drought. This will limit the possible increase of animal productivity, even if grassland productivity should increase in the future in Vercors. On the other hand, increasing of season length in altitude should allow increasing the period where animal can be put in the mountain during summer. Hence current animal should be maintained in the future.

CAMELEON project is the first attempt to provide reliable and comparative regional-scale simulations of carbon dynamics in European mountain ecosystems that incorporate our best ecological knowledge of these biodiversity hot-spots. It is a milestone towards a better understanding of climate and land use change impacts on carbon sequestration in European mountains.

2. Work progress

The description of the work progress is given by workpackage. For each of then a description of the work done during the project is given.

WP110 Mapping the cover over the three sites

A first step was to define a common classification of the land cover and a scale for the mapping that reach both the constraints and characteristics of each site and the requirements for the modeling part of the project. Nine classes have been defined (Table 1). Land cover maps are provided as fractions of each class within a 1km grid cell, irrespective of the spatial configuration within the grid cell. The minimum mapping unit was set to 5 ha (Austria) and to a much finer resolution (France). Maps are produced using a projection system ETRS89-LAEA (EPSG: 3035) that is common to the three sites.

class	code	remarks
alpine grassland	1	primary, 'natural' grasslands above the tree line
extensively managed grassland	2	on slopes and higher altitudes; little fertilization
intensively managed grassland	3	in valley bottoms; fertilized
shrubland	4	dwarf-pine shrub, green alder, heathland
deciduous forest	5	more than 90% deciduous trees in the forest stand
mixed forest	6	both less than 90% deciduous and coniferous trees in the stand
coniferous forest	7	more than 90% coniferous trees in the forest stand
others (rock, urban, water, etc.)	8	"unvegetated" areas
noData	9	areas outside the study area, but inside the raster grid

For Vercors, for instance, vegetation distribution within the study area closely mirrored the underlying topography and land use. Vegetation cover consists of a mosaic of deciduous and mixed forest (*Fagus sylvatica* and *Abies alba*) at lower elevations, coniferous forest (composed primarily of mountain pine i.e. *Pinus uncinata*) and subalpine grassland at mid to upper elevations, and alpine grassland and sparsely vegetated ridge crests at the highest elevations. The best represented topographic classes of the study area included west-facing, moderately sloped (<10° or 10-30°) zones situated between 1500 and 1800m and it is within these classes that the bulk of the vegetation shifts occurred Within this area, land use is the primary driver that can account for the fine scale distribution of forests, shrublands and grasslands (see below). We did not find climate variables or soil parameters that can explain this land cover variability. Accordingly, we developed predictive model of vegetation change based on the extrapolation of historical trends (see below).

Climate data collected within the RNHPV from 1959 to 2009 indicates an approximate 1 °C rise in mean annual temperatures over this time period. Precipitation trends over recent decades within the RNHPV are highly variable, showing no discernible pattern from 1959 to 2009. Mean annual temperatures in the RNHPV from 1959 to 2009 showed three distinct phases (Figure 2.5). From 1959 to 1980, there was a period of gradual rise in annual means, followed by a sharp increase between the early 1980s and early 1990s, followed by another period of gradual rise between roughly 1990 and 2009. Expansion in conifer forest relative to this pattern was linear and far less stochastic. Between 1978 and 1993, there was a rapid rise in conifer expansion that corresponded with rising temperatures during the same period. Mean annual precipitation levels over the same period provided a less coherent trend relative to temperature. The period of rapid conifer expansion between 1978 and 1993 aligned with a sustained stretch of dry years, which suggests that linear conifer expansion was impervious to lower precipitation levels. Temperatures in the RNHPV between 1500 and 1800m were on average 1°C lower than the study area average. As shown in the graph comparing mean annual temperature to overall conifer expansion, the period of more rapid conifer expansion between 1978 and 1993 aligned with accelerated warming during the same period.

WP120 Mapping of historical land cover

Historical land cover maps have been produced by means of visual interpretation or segmentation techniques of aerial photographs. Land cover maps have been linearly interpolated between the dates available for each site. Table 2 gives a summary of available images for the three sites. For modeling purpose, maps have been projected as fraction on the 1km grid cell used by ORCHIDEE. The maps are also available at a higher resolution and with a more detailed number of vegetation for each site (e.g. 5m for Vercors)

Site	Available dates
Stubai Valley	1954,1973,1988,2003
Vercors	1948,1979,1995,2009
Alinya	1956,2010

For Vercors, for instance, thirty 1000 dpi, 230x230mm aerial photos were obtained from the Institut de Géographie Nationale (IGN) and orthorectified in ErdasIMAGINE 9.1. A direct linear transformation model was used to align 1993 images with a 25m resolution Digital Elevation Model (DEM) and a 1m resolution 2009 reference mosaic. A minimum of twenty ground control points were established per image, and maximum Root Mean Square Error tolerance was set at 0.05. Individual images were stitched into a mosaic using a weighted seamline with a segment length of 10 pixels and a bounding width of 200 pixels. Two mosaics were created: one "Dark" and one "Light," in order to offset contrasting radiance values associated with different flight missions. Histogram matching was applied in order to further homogenize inter-image pixel values. Finally, completed mosaics were rubber sheeted in ArcGIS 10, using a minimum of 100 ground control points per mosaic. Mosaics were classified into a forest/nonforest raster layer using eCognition version 8.3. Binary rasters were then exported to ArcGIS and corrected manually via comparison with the original image mosaics. Forest binary layers were then overlayed with a 1:5000 vegetation map, created in 2003 by the Conservatoire Botanique National Alpin (CBNA). The forest/non-forest layer allowed for division of the study zone into two parent classes.

The CBNA map subsequently allowed for pixels to be further classified into sub-classes that consisted of coniferous forest, deciduous forest, mixed forest, extensive grassland, alpine grassland, rock and no data. A maximum likelihood function was used to give each 5m pixel a probability of belonging to one of the seven classes, and the class with the highest probability was then assigned to the pixel. The rock layer was fixed as a constant for all four dates, as the 60-year study period was not long enough to allow for observation of primary succession change.

For Alinyà, historical land cover maps have been generated by visual interpretation of georeferencing aerial photographs taken in 1956 (American flight, series B) and those taken in 1990 (orthophotos of Catalonia) visualised though the Historical Web Map Service from the Institut Cartogràfic de Catalunya (http://historics.icc.cat/lizardtech/iserv/ows). The process of generating the historical land cover cartography consisted of the normalized photointerpretation based on morphological criteria (scale 1:50000). The categories of the legend were established from the results of the current cartography of that region that has been obtained based on the map of habitats in Catalonia acquired from "CERBIV-La Generalitat de Catalunya" (2006). Using the orthophotos from the year 1990 and the dataset with the corresponding legend, a photo interpretation and digitalization of the land cover of the study area were carried out, followed by a validation of the final output map. Once the map of 1990 was ready, and based on the photographs of 1957, we performed another downdating process and thus the final map was generated and later validated.

WP130 . Dynamics of Plant Functional Diversity

The objective of this workpackage was to estimate Community Weighted Mean (CWM) of traits for each of vegetation class. A first step of this task was to synthetize the available vegetation relevés in each study area and for each land covers class. Then Partners have agreed upon a list of relevant plant functional traits that could be used for biogeochemical modeling using ORCHIDEE. Two plant traits have been considered: Specific leaf area and Leaf Nitrogen Content from which we derived the maximum rate of carboxylation (Vcmax) following Kattge et al. 2009.

For Vercors we assembled a database of 254 vegetation relevés for which the visual abundance of species cover was estimated following a 6-levels scale:]0%,1%],]1%,5%],]5%,25],]25%,50%],]50%75%] and]75%,100%]. We used the median of each class to derive a percentage of cover for each species, i.e. 0.5%, 3%, 15%, 37.5%, 62.5% and 87.5%, respectively. The traits values used for each species was based on site measurements for 60% of species. Complementary trait data were retrieved from the Androsace database (a local DB of plant traits) and the TRY DB (Kattge et al., 2011).

For each relevé, we estimated a Community Weighted Mean (CWM) of trait as described in (Violle, C., M. L. Navas, D. Vile, E. Kazakou, C. Fortunel, I. Hummel, and E. Garnier. 2007. Let the Concept of Trait Be Functional! Oikos 116:882-892.). For each land cover class, we calculated the mean, the standard deviation and the range of CWM based on all the relevés available for this class.

At Stubai Valley the following approaches were chosen to identify the CWM and CWSD of SLA and leaf nitrogen content: 1) Across four differently managed grasslands at the valley bottom and the subalpine belt species-specific trait values previously measured at the Stubai sites and contained in a database (cf. Kattge et al. 2011) were combined with abundance estimates of the respective species to calculate CWM of SLA and leaf nitrogen content. Uncertainties in species abundance were projected onto two different CWM estimates, providing an uncertainty estimate for CWM trait values. 2) To further constrain traits values for grassland sites data for CWM and CWSD for a typical managed and an abandoned mountain grassland in the subalpine belt were made available from the VITAL project (Grigulis et al. 2013), where at each site 12 50x50 cm quadrats, as distributed over three replicate blocks, were sampled at peak biomass and traits were measured following the protocol of Cornelissen et al (2003). Surveys of vegetation composition were performed using the BOTANAL method to estimate species relative biomass (Lavorel et al. 2008). CWM was calculated as described by Garnier et al. (2004), CWSD was calculated based on the three replicate blocks. 3) For the dominant tree species (*Picea abies, Larix decidua*) SLA and leaf nitrogen content were measured for sun and shade crowns of five replicate trees at two representative elevations (1300 and 1800m). 4) for other vegetation units, which make up a smaller percentage of vegetation at Stubai Valley a literature survey was conducted and published ranges of traits values were reported.

For Alinyà, ten vegetation units were selected to sample the main species and their functional traits. For each community type, 1 to 3 different patches were selected. The community types consisted of: *Pinus sylvestris* L.*, Pinus uncinata* Miller*, Pinus nigra* J.F. Arnold spp. *salzmanii, Quercus ilex* L. spp. *rotundifolia, Quercus robur* L.*, Buxus sempervirens* L.*, and Juniperus communis* L. spp. *communis.*
The variables measured in the field were: tree diameter at breast height (DBH), and tree height. Tree species represent an additional variable. Twigs and leaves were collected in the field. A total of 2 twigs (sun vs. shade) from each tree were sampled. Leaves were collected from the twigs according to two different parameters: light (facing south, in bright conditions) and shade (facing north, shaded by other branches or by the trunk). From each branch, 6 leaf samples were taken; 3 exposed to light conditions and 3 shaded leaves. Leaves were collected at a comparable height (approximately 3 m) for tall trees, as for the small trees such as *Buxus sempervirens* and *Juniperus communis* spp. *communis*, the leaves were collected near the top of the tree. A minimum of 10 leaves per species, from at least 5 individuals were collected according to Cornelissen et al. (2003). And since many species exist in the same site, each species was sampled in the plot representing its relative best-growing conditions. 2 leaf samples (1 in light conditions and 1 in shade conditions) from each site were sent to laboratory for the analysis of Carbon and Nitrogen.
Based on the data obtained from the field, the following traits were calculated: SLA, LDMC, LNC, and LCC. The trait values of 62 dominant species in the vegetation communities in Alinyà which were used were partly based on site measurements, whereas the remaining were acquired from literature, the CARBOMONT database, the LEDA traitbase (Kleyer et al. 2008), and the CLO-PLA traitbase (Klimešová & Klimeš 2005). At species level, we calculated the relative abundance of each species per community (mixed forest, deciduous forest, alpine grassland, etc.). For each land cover class, the mean, the SD and the range of CWM were calculated.

WP210 Data synthesis of in situ flux measurements

Flux data and ancillary data were provided to the database of the project coordinator. Flux data included 1) eddy covariance data for the anchor sites at Stubai and Alinya, 2) chamber-based NEE data for additional grasslands at Stubai, covering a gradient of land management and altitude, 3) soil respiration data for Stubai and Alinya. Ancillary data include continuous (micro) meteorological time-series and information on leaf area index, biomass and management. The data sets were previously synthesized in the papers by Wohlfahrt et al.

(2008a,b) (eddy covariance data), Schmitt et al. (2010) (chamber-based NEE data) and Bahn et al. (2008) (soil respiration data). Unfortunately no flux-based data exist for Vercors.

At the Stubai Valley the following CO_2 flux data and related ancillary data were provided as model input:

1) For the eddy covariance site at Neustift data were provided as published in Wohlfahrt et al. (2008), see Fig 1.1a
2) For six grassland ecosystems, including meadows pastures and abandoned grasslands at different elevations, NEE and ancillary data were provided as published in Liu et al. (2008) and Schmitt et al. (2010), and complemented by some further more recent unpublished measurements, see Figs. 1.1b 1.2 and 1.3
3) For four grassland ecosystems at the valley bottom at in the subalpine belt soil respiration data were provided as published by Bahn et al. (2008), Bahn et al (2009), Vargas et al. (2010) and further more recent unpublished measurements (Ladreiter et al., in preparation).

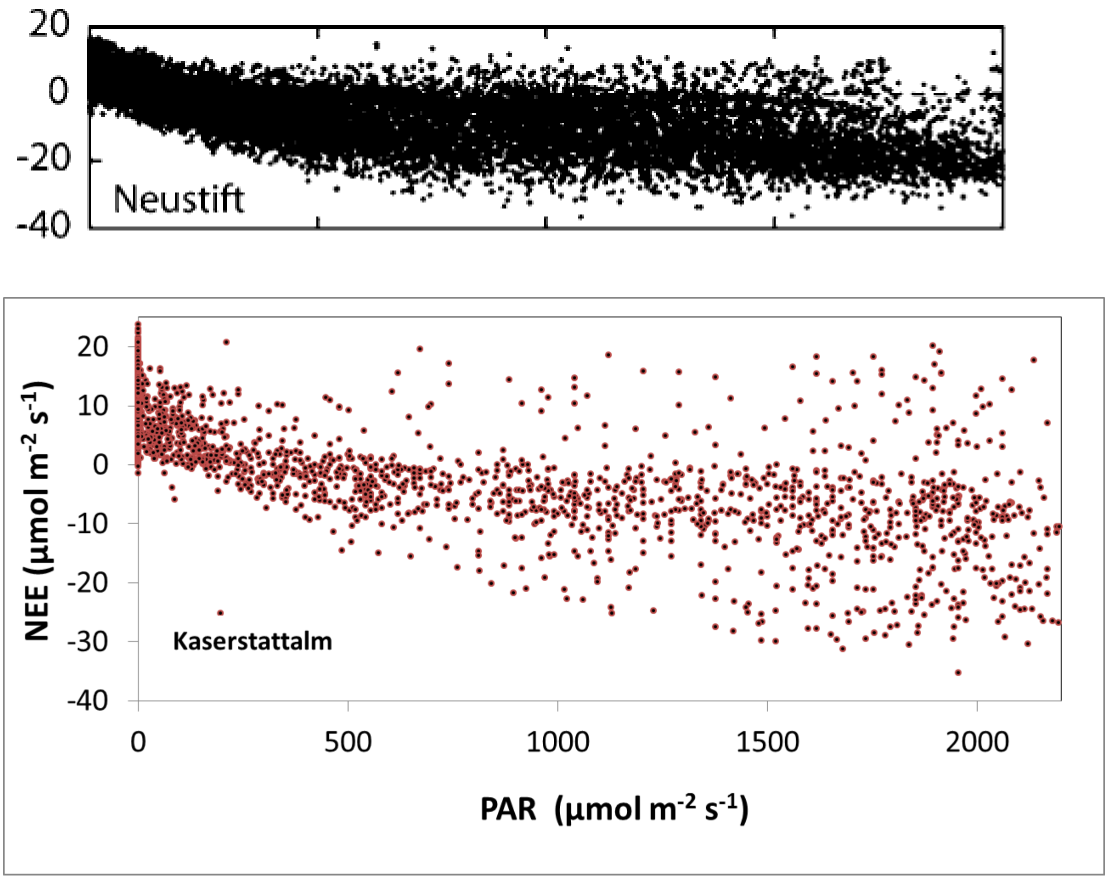


Fig.2.1 Net ecosystem exchange of CO2 as a function of photosynthetically active radiation at the Neustift valley bottom, eddy covariance data; Wohlfahrt et al. 2008) and Kaserstattalm (1850m, chamber data, Schmitt et al. 2010 and additional data)

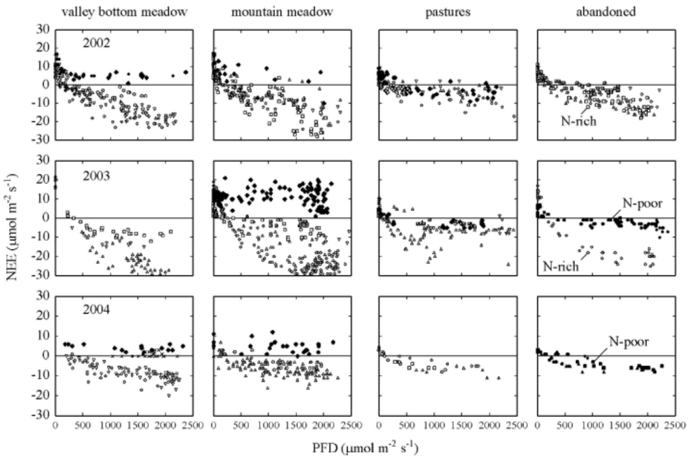


Fig 2.2 NEE in relation to photon flux density (PFD) for two meadows, two pastures and two abandoned grasslands during the growing seasons 2002–2004. Negative values denote net CO2 uptake by the canopy, positive values a net loss of CO2 to the atmosphere. Each data point shows a single set of chamber measurements (from Schmitt et al. 2010).

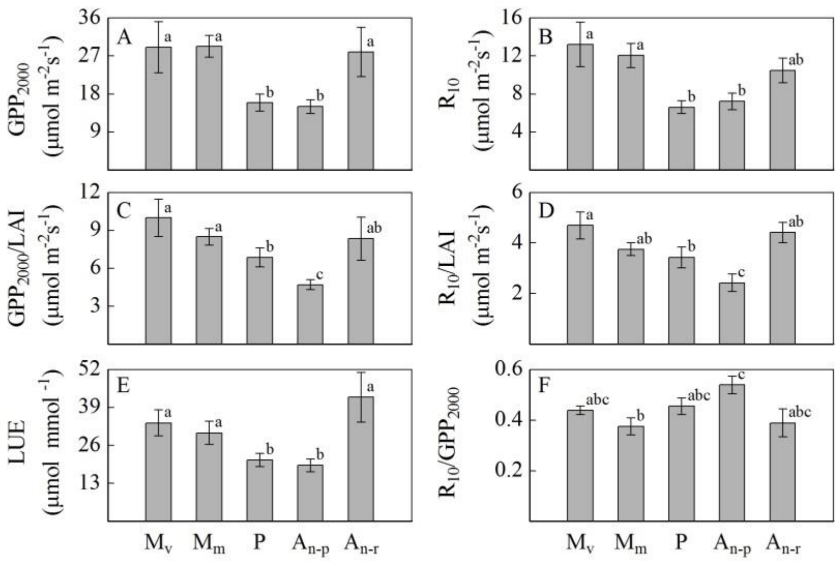


Fig 2.3 Mean peak season values of (A) gross primary productivity per unit ground area at a photon flux density of 2000 µmolm−2 s−1 (GPP2000), (B) ecosystem respiration at a reference temperature of 10 C (R10), (C) GPP2000 per unit leaf area, (D) R10 per unit leaf area, (E) light use efficiency (LUE), (F) R10/GPP2000 at optimum LAI. Sites are indicated as: Mv (valley bottom meadow), Mm (mountain meadow), P (pastures), An−r (nutrient-rich abandoned grassland), An−p (nutrient-poor abandoned grassland). Significantly different means are indicated by different letters (oneway ANOVA). Error bars represent standard errors (from Schmitt et al. 2010).

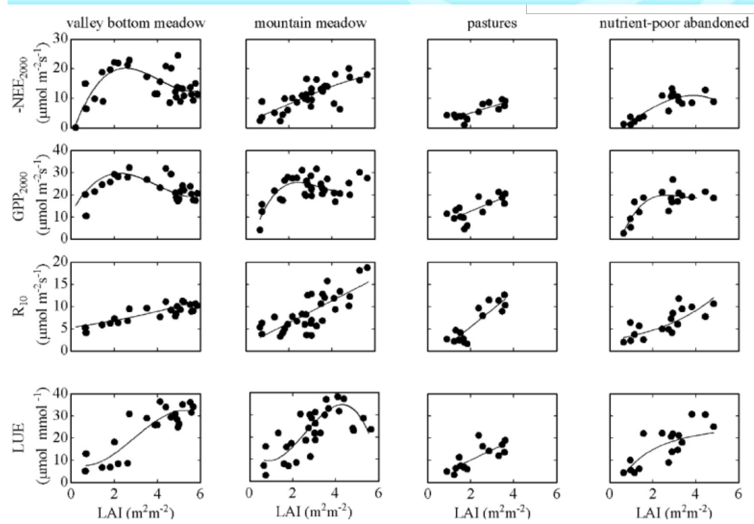


Fig2.4 Relationships between the net ecosystem CO2 exchange at a photon flux density (PFD) of 2000 µmolm−2 s−1 (NEE2000), the gross primary productivity at a PFD of 2000 $\mu molm^{-2}$ s^{-1} (GPP2000), the ecosystem respiration at a reference temperature of 10 C (R10) and the light use efficiency (LUE) in response to leaf area index (LAI) at differently managed grasslands at Stubai (from Schmitt et al. 2010)

WP220 Data synthesis on soil carbon

This is the only workpackage for wich it was not possible, unfortunately, to achieve partially the initial objective. Indeed it was possible to collect the soil data already available for instance in the frame of the PASTUS project for pyrennees and some soil data available from FLUXNET for Stubai. But it was not possible to obtain others data from Stubai and Vercors. The reason come from the fact that these data do not belong to the projects parterns but from others groups. And it was not possible to share the data with these others groups even if a lot of effort have been done to obtain the data.

WP230 Remotely-sensed vegetation dynamics

1. Evaluation of remote sensing data to study vegetation dynamics on the study sites

The potential of several remote sensing products to infer vegetation dynamics over the study sites have been evaluated in this work package:

- MODIS daily reflectance in the blue, red and near infrared wavebands, corrected from the directional effects, at 5km and over the period 2000-2010.
- AVHRR NDVI-LTDR daily data available at 5km from 1981 to 2000.
- SPOT-VGT decadal reflectance and NDVI products at 1km from 1998 to 2011, from the S10 and D10 syntheses (http://free.vgt.vito.be/).
- CYCLOPES biophysical products of LAI, fAPAR and fCover (with attached uncertainty) available every 10 days from 1999 to 2007 (Weiss et al., 2007).

Because of the larger spatial resolution, 5 km products are more affected by cloud contamination than the 1 km ones, especially in mountain areas. The analysis of the number available observations in AVHRR and MODIS products have shown to be insufficient to conduct further analysis. For this reason, the AVHRR and the MODIS data were not considered further, in spite of the advantage of the time length of AVHRR records.
The comparison of fAPAR and LAI products (from the CYCLOPES project) with the SPOT-VGT NDVI derived products have shown good agreement with respect to the temporal profiles, in particular fAPAR and NDVI products were strongly correlated. The phasing of the growing season (start, end and length) was captured similarly by the different remotely sensed products, the senescence in LAI being however generally in advance as compared to fAPAR or NDVI. Also, the magnitude of the growing season was more important in LAI as in the other products.
Nevertheless, as appealing as CYCLOPES products were (they are provided with a slight higher temporal resolution, and they relate directly to variables that are simulated by vegetation models), the lack of data in winter and spring in Stubai and Vercors precludes their use for a generic analysis for the three study area.
Strangely, NDVI D10 (with correction of the directional effects) product exhibits high jumps in its temporal variation for some dates whereas these features are mitigated in the S10 products. This likely result from some atmospheric correction problems that are magnified by the directional correction in D10.
For the above mentioned reasons, only the SPOT-VGT NDVI S10 products were considered in the following analyses.

2. Inter-annual variations of vegetation dynamics

The analysis of the inter-annual variations of the vegetation dynamics over the three study sites is undertaken by the determination of the start of the growing season the analysis of its year to year variations. The approach relies on the algorithm described in Bacour et al. (2006) and Maignan et al. (2008). It is based on a temporal interpolation of the radiometric signal of interest using the procedure described in Thoning et al. (1989) and is applied on a per pixel basis. The procedure allows extracting a smooth curve, a mean seasonal, from which are inferred the dates of leaf onset. The latter are defined as the date when the smooth curve crosses the trend curve upward, which is equivalent to searching for the zeroes of the de-trended time series. The approach applied to AVHRR data at coarse resolution has shown providing valuable information on the inter-annual onset anomalies, consistent with *in situ* observations, in spite of however lower agreement in mountain areas considering the coarse resolution of the remote sensing data used (Maignan et al. 2008).
In the following, the approach is applied to 12 years of SPOT-VGT NDVI S10 data (1999 to 2010) over the Alinya, Stubai and Vercors, areas, as well as to the ORCH-GM simulations that is used here as an reference dataset.

The first year of this work package has mainly been dedicated to recover and evaluate the most relevant satellite products for studying vegetation and snow cover dynamics over the three sites. The following products have been extracted for Stubai, Vercors and Alinya:

- MODIS daily reflectances in the blue, red and near infrared wavebands, corrected from the directional effects, at 5km and over the period 2000-2010. These reflectances are used to monitor the interannual variations of the seasonal vegetation cycle of thanks to vegetation indices (NDVI, EVI and DVI).
- AVHRR NDVI-LTDR daily data available at 5km from 1981 to 2000
- SPOT-VGT decadal reflectance and NDVI products at 1km from 1998 to 2011

- CYCLOPES biophysical products of LAI, fAPAR and fCover (with attached uncertainty) available every 10 days from 1999 to 2007

The 1km satellite products have been re-projected on the ETRS89-LAEA system.
The quantitative estimation of phenological parameters of vegetation dynamics (dates of leaf onset and senescence mainly) is quite challenging in mountainous areas because of relatively high cloud occurrence. 1km satellite products are then more prone to provide a sufficient temporal monitoring of the land surfaces than 5 km satellite observations due to a lesser probability of cloud occurrence in high spatial resolution pixels. The temporal variation of the vegetation activity available through these satellite products at 1km will further be used in WP240 to optimized ORCHIDEE phenological parameters.
The study of the relationships between plant phenology and climate variability requires maps of meteorological fields that will be available in WP310.

WP240 Simulation of current C fluxes and stocks

This task can be separated into two main subtasks:

1. From simulation at site to regional level, Comparison calibration and assimilation of collection of data from WP 210,WP220, WP230
2. Evaluate the uncertainties on functional traits (value and variability obtained from WP130) on simulated carbon stocks and fluxes.

From in-situ data provided by WP210 from the two sites where flux tower are installed: Stubaï and Alinya, it was possible to simulate the main stocks and fluxes and then evaluate and improve the ORCHIDEE model.
In parallel, the ORCHIS assimilation system for ORCHIDEE has been improved in order to:
• Better take advantage of time series of satellite products of vegetation activity to estimate few key phenological parameters.
• Allow the separation of nighttime vs daytime flux measurements. This distinction is very important to improve the constraints on the parameters to optimize brought by the various types of observations, considering that nighttime observations mainly controls the heterotrophic respiration of the ecosystem while being associated to higher observation errors
This optimized results was there compared to traits data to see if there is convergence between improved traits parameters obtained after model optimization and estimated community level traits values.

For the second task the estimated community weight traits mean and standard deviation was introduced in the model to evaluate the related uncertainties in estimated stock and flux from ORCHIDEE We also accessed the impact on spatial variability.

WP310 Climate change and impacts on carbon dynamics: past-present-future

First step for this task was to prepare a coherent high resolution climate forcing for the three regions as such kind of data does not exist now to date. This is also required by others task (e.g 110, 230). The method was based on a combination of two climate datasets. The first one is a climate dataset that was provided in the frame of CEXTREM and GHG-EUROPE FP7 european project. It is an harmonized climate forcing for Europe at a 0.25°x0.25° resolution covering the historical period (1901-2010, based on ERA-WATCH climate reanalysis) and a future climate scenario (2010-2100, A1B baseline). The second one is the monthly WORDCLIM global 1km climatology. The WORLDCLIM is then used to provide a spatial disaggregation of original 0.25°x0.25° data to 1km, the grid used in the project. We initially expected to use at least two different climate scenarios for the future. But we limited only to the A1B scenario that was the only one available for the harmonized datasets. We though to use others datasets, in particular the new ISI-MIP datasets that are based on new AR5 scenarios but there is two big limitation compared to the dataset we used. First it is not an harmonized dataset. It means that climate for historical period is climate simulated by the model and is not then the “real” climate. We could eventually use it only for future period but then model bias would conduct to a discontinuity between historical and future period. Another limitation is related to the fact ISI-MIP is only at a 0.5°x0.5° resolution and is only based on statistical desegregation on large scale model at more than 2°x2°. So desegregation to 1km in this case is meaningless (in comparison the used dataset is based on a regional model simulation with a native 0.25°x0.25° resolution

Second step of this task was to make a series of simulations with ORCHIDEE fixing constant some climate parameters and letting the others parameters variable to attribute the role of each parameter in the observed variability and trends

WP320 Land use change and impacts on carbon dynamics

For this task, simulations are based on the same climate forcing than for WP310. But here we used the land cover maps provided by WP120 and WP410. In the same way than for previous task, simulations based on fixed land cover and including land cover change was done to attribute the role of land cover change to fluxes and stocks change compared to impact of climate change.

WP330 adaptation of grassland management to climate and land use change

Thanks to new improvement of ORCHIDEE model obtained in the frame of CAMELEON project, it was possible to add a new important task not anticipated at the beginning of the project about simulation of the adaptation of grassland management to climate and land use change.
A new version of ORCHIDEE: ORCHIDEE-GM (for grassland management) has been developed to improve the representation of pasture management and functioning. This new version was based on the inclusion of Animal and management modules from PASIM grassland model into ORCHIDEE. This allow to represent the functioning of both grazed and cut grassland and simulate animal production (meat and milk for instance). Moreover, Vuichard et al 2007 included in PASIM a module that allows estimating the maximum sustainable animal density. It is based on the hypothesis of a self-sufficient system (i.e animal are only feed by local resources) and that the fraction between grazed and cut grassland can be variable. The model then estimate the maximum animal density that fit the condition that harvested forage is able to feed the animals where they are not in the field. The limitation of this method is that it can only be applied to a steady climate. So recently we improved the method to be able adapt animal density to climate change. The principle of the method is that from a fixed animal number at the beginning of the year, depending of climate condition, we will have an excedent or deficit of herbage. Knowing this excedent/deficit, it is possible to estimate how much supplementary (resp. to much) animal can be feed. As we assume that farmer we not react instantaneously to year to year variation of climate we do a progressive change of animal density. Hence we will have an adaptation of animal density to long term climate change. This method was designed to work at the scale of each pixel. In the frame of CAMELEON we also adapted the method to take into account for the different grassland systems found of the three sites and to take into account for the land cover change. For Stubai and Alinya we have systems where animals are put on extensive grasslands (ExtGL and AlpGL) during the summer whereas Intensive grassland is cut and used to feed the animals at barn. So the system is not

very different from system considered in our optimized system except that cut and grazed field are not located on the same pixels (and then have a different climate) and that fraction of grazed and cut grassland is fixed by land cover map and change with time. For Vercors we have a very different and more complex system as there are only grazed grassland during summer and while animals are grazing in the Mediterranean Crau plain during winter with eventually some supplementary forage from cut grassland also in the Crau. This is a very interesting system as, obviously, Crau and Vercors will experience a very different climate change. These different systems were then implemented in the model and were used to simulate the optimized animal density and its evolution with climate and land use change.

WP410 Mapping of future and cover

This task was done in close collaboration with local stakeholders. The objective was to define land cover change trends expected by the different stakeholders local doing several interviews giving them information about expected climate and socio economics change for their area

- The Stubai case

For Stubai, two workshops (each half a day) were held with stakeholders (local farmers) to determine future land-use under given socio-economic and climate scenarios.
Each workshop was held with 4 local farmers, representing

- traditional economic farming (small farm with stock breeding and high productive dairy cows; part-time farming);
- modern economic farming (large, innovative farm aiming on economic growth; full-time farming);
- traditional ecologic farming (small, traditional farm with organic production; part-time farming);
- Modern ecologic farming (strong ecological interest, direct marketing of high quality products).

Local and global socio-economic scenarios (see below) were presented together with 5-years and 20-years climate scenarios (see below) based on IPCC storylines to the stakeholders. A worst case 20-years climate scenario was developed during the first workshop. Large maps of the study area 'Stubai Valley' were produced from aerial photographs and given to the stakeholder group. They were then asked to delineate future land-use according to the assumptions of the presented scenarios. The stakeholders of the first workshop worked with the global socio-economic scenario, the stakeholders of the second workshop worked with the local socio-economic scenario (in combination with the climate scenarios).
The outputs of the workshops were therefore

- land-use for 2017 according to the local socio-economic scenario and the 5-year climate scenario
- land-use for 2017 according to the global socio-economic scenario and the 5-year climate scenario
- land-use for 2032 according to the local socio-economic scenario and the 20-year climate scenario
- land-use for 2032 according to the global socio-economic scenario and the 20-year climate scenario
- land-use for 2032 according to the local socio-economic scenario and the 20-year worst-case scenario
- land-use for 2032 according to the global socio-economic scenario and the 20-year worst-case scenario

The local socio-economic worst-case scenario was stated to be identical to the 20-year climate scenario.
The global socio-economic worst-case scenario was stated to be identical to the 1954 land use.
The spatial information was digitised and integrated into a GIS. For further processing the data was transferred to cell-wise information according to WP120. Future land-use according to the scenarios was finally provided in table format as fractions inside the pre-defined 1km raster cells for the Stubai Valley.

- **SOCIO-ECONOMIC SCENARIOS**

Local socio-economic scenario

Settlement development: An increasing number of the people living in the lower front part of the Stubai Valley are commuting to Innsbruck for work. The limited space is used at best to fulfill the regulations of the regional planning authorities for compression of the urban area. The inhabitants of the upper back parts of the valley made efforts to expand sustainable tourism. Private rooms are widespread and made available by local people to counteract the development of giant hotels.
Tourism and recreational activities: The region profits from an increasing demand for local products by the steadily increasing all-year tourism. The strategy of an environmentally-sensitive and sustainable tourism is pursued (farm holidays, hiking tourism with offers for hikes on alpine pastures in summer, bobsleigh and ski tours in winter).
Product price development: Locally produced groceries are increasingly demanded. Therefore prices for products that are produced according to biological regulations and with protected indication of origin are rising. Prices for conventionally produced products are decreasing. Local processing enterprises are developing or are maintained (e.g. butchery, alpine dairy)
Subsidies: As a result of the new CAP Reform (Reform of the Common Agricultural Policy), farmers are ongoing primarily funded by the Rural Development Fund (second pillar). Money from direct payments (first pillar) has only little influence on the income of the farmers.
The national subsidies are further bound to environmental specifications. Besides the existing requirements of the Austrian Program for environmentally friendly agriculture (ÖPUL), the society demands for specific regionally balanced ecosystem services. Specific regional subsidies are co-financed by the regional tourism association. The farmers fulfill the requirements to gain access to these subsidies.
Public support: The local administration contributes to the regional development through financial support for infrastructure (road maintenance, commonly usable processing and marketing facilities) and by providing agricultural tools and equipment for cultivation.

Global socio-economic scenario

Settlement development: An increasing number of the people living in the lower front part of the Stubai Valley are commuting to Innsbruck for work. The upper back parts are dominated by mass tourism and giant hotels are negatively affecting the townscape.
Tourism and recreational activities: The farmers are trying to manage their agricultural land in the alpine region according to the recreational demands of tourists and local people. Therefore, only few selected areas are managed. The role of the farmers as producers of groceries retreats in the background. Seasonal advertising focuses in winter on skiing and in summer on outdoor adventure tourism (example "Area 47").
Product price development: Both residents and tourists select products primarily on the basis of their price. Origin and quality of the products are irrelevant for the buying decision. The local food production is not able to keep up with the prices that are developing on the global market. The price for milk declined dramatically due to the end of the milk quota (-20% for conventionally produced milk and for hay milk, -10% for organic milk; -15% for cow and sheep

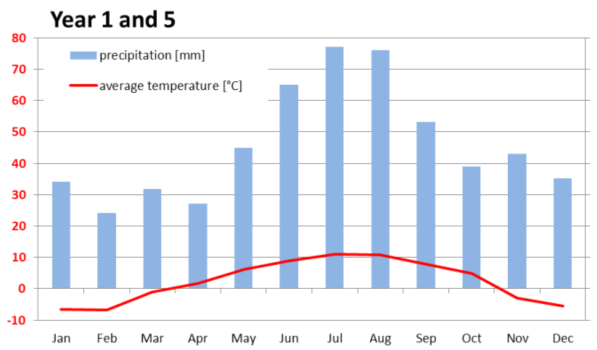
meat). The agricultural products are processed in highly centralized factories outside the valley.

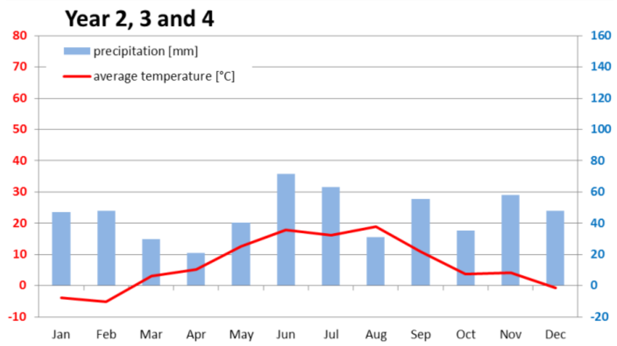
Subsidies: Agricultural subsidies are still paid to maintain agriculture in the Stubai Valley but are reduced by about 20%. Every farmer receives a small basic income that can be increased by providing proven global ecosystem services, like biodiversity, water quality, plants for CO2-sequestration, etc.

- **CLIMATE SCENARIOS**

<u>5-year climate scenario</u>

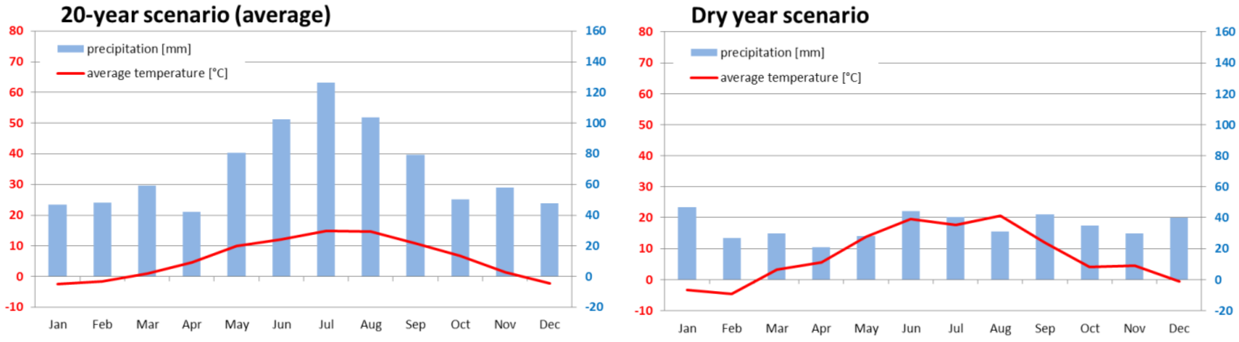
Dry years are alternating with normally wet years. Year 1 shows usual conditions for the Stubai Valley with ca. 1100mm precipitation per year and solid snow cover between December and April, resulting from ca. 300mm precipitation as snow (comparable to the mean conditions between 1991 and 2000). Year 2, 3 and 4 are characterized by a significantly shorter period of solid snow cover and precipitation in winter falls almost exclusively as rain. Spring-time conditions are dry with very little run-off from the mountain streams due to missing melting water from the tops. The summer is characterized by little rainfall (ca. 250mm) and high temperatures (comparable to 2003). Vegetation below 1300m experience extreme drought stress and hey yield is only 50% of the usual amount. The little time of snow cover and the high temperatures reduce side-line incomes from winter tourism by about 50%, as tourists are visiting more snow-reliable regions above 2500m (Switzerland, France). The conditions of the pistes in the skiing areas in the Stubai Valley are poor and also the infrastructure in the glacier regions is suffering from melting permafrost grounds. Year 5 is climatically again a usual year and bookings are increasing, but are breaking-down again in the years 7 to 9.





<u>20-year climate scenario</u>

The mean temperature rises from 2.4°C to 5.8°C. Precipitation decreases from 1100mm to 845mm per year (summer: ca. 570mm, winter: ca. 280mm). Average years produce little loss of yield (ca. -10%). The higher temperatures during winter result in less snow and snow cover becomes unreliable below 1500m. The conditions for artificial snow are getting poorer. This typical trend with increased temperatures and decreased precipitation is exaggerated during even drier years that are reducing yields to about 50% in summer and lead to warm winter months with very little snow; these drier years are occurring in seven out of ten years. Ski tourism is only profitable above 1800m. (Notice: A ski resort needs about 100 days per year with more than 30 cm of snow in seven out of ten years to be profitable; see Abegg 1996, Steiger 2007).



Worst-case 20-years climate scenario

Most years are very dry, with climatic conditions similar to the dry years of the 20-years scenario. Because of little snow fall in winter and dry springs, hey yields rarely allow for agricultural production. Both summer and winter tourism crashed.

- ## Vercors case

We developed a hierarchical linear mixed model to analyze changes in the forest-grassland ecotone over the last 60 years and to derive land cover scenarios. Our longitudinal data set comprised N grid cells for which we estimated a Forestation Index at the four historical dates. The normalized Forestation Index (FI) was calculated for pixel (i) and for each date (j) using the following formula:

(i) $FI_{ij} = (F_{ij} - NF_{ij}) / (F_{ij} + NF_{ij})$

where F represents forest area and NF represents grassland area. FI values ranged from -1.0 (non-forested) to 1.0 (fully forested), and forested pixels were defined as those with an FI value > 0.

We used this linear mixed model framework to extrapolate forestation index values for the next two decades and to map land cover in 2030. This scenario was used a baseline for discussion with stakeholders.

Semi-directed interviews with stakeholders (shepherds, land managers) allowed us to put the question of forest expansion in a broader context (see Figure 2.6). Several external drivers outside of the control of reserve officials have the potential to cause increasingly concentrated grazing: (1) more frequent droughts in southern France may reduce the productivity of Mediterranean pastures and incite shepherds to bring their flocks to mountain areas such as the Vercors; (2) the recent re-emergence of the wolf in the Vercors has prompted shepherds to concentrate their flocks in open areas where it is easier to survey sheep and also to confine flocks at night (Espuno et al. 2004); (3) shepherds' growing demand for comfort tends to increase the proportion of time spent in the vicinity of cabins and finally (4) sheep races have been selected for increased weight at the expense of water stress tolerance, which renders flocks more dependent on water sources. All these factors will tend to increase the contrast between open pastures in the vicinity of shepherds' cabins and surrounding densely forested areas.

The Reserve Naturelle des hauts Plateaux du Vercors does have the ability to counteract grazing concentration by authorizing shrub burning and removal and also by implementing a network of equipped water points in order to avoid localized high stocking rates. In this scenario, land managers tend to reconsider their initial conservation priority (i.e. the protection of a renowned mountain pine forest) and to implement proactive management strategies in order to ensure landscape heterogeneity. The implementation of such a spatially heterogeneous disturbance regime will allow restore/maintain grassland habitat beyond the immediate vicinity of shepherds' cabins.
We empirically modified the estimators of the linear mixed model to take into account these contrasting scenarios. This leads either to accelerate the trends observed over the last 60 years or alternatively, to reduce the forest expansion at the expense of pastures.

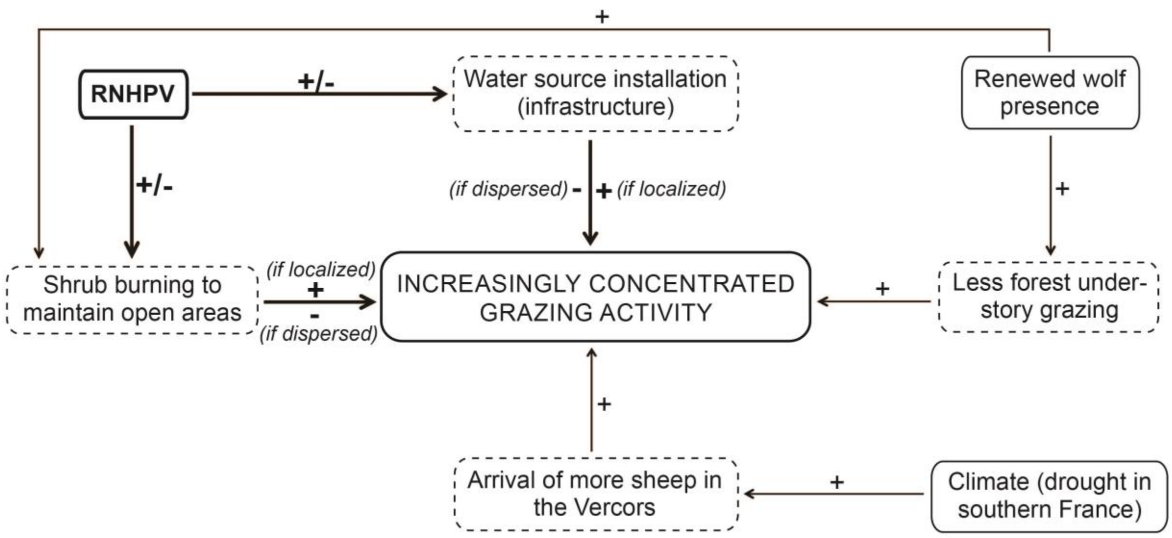


Figure 2.5 Anticipated near-term causes of increasingly concentrated graeing practices in the RNHPV. Solid outlines represent external drivers, while dashed outlines represent conditions affecting the spatial distribution of sheep grazing. Bold arrows indicate conditions that the RNHPV has the potential to influence through conservation decisions.

- The Alinyà case

- **SOCIO-ECONOMIC SCENARIOS**

Scenario 1: Status quo - gradual reduction of farm price support by CAP; continuing restrictive planning policies

The basis of this scenario is that the process of CAP modification occurs on an incremental path where the current basis of agricultural support is maintained but with increasing amounts being channelled away from production-related support, towards agri-environmental and direct income measures. There is a continuation of the gradual introduction of policies to encourage the rural economy but with little change in existing restrictive planning controls on development. In summary this scenario represents a minimalist change policy

Scenario 2: Reduce farm prices (rapid reduction of agricultural price support and a switch to environmental or area-based payments); continuation of restrictive planning)

Under this scenario the decoupling of farm support from farmer's production decisions is taken to its logical conclusion through the phasing out of price guarantees and their replacement by production-neutral, decoupled payments, under pressure from the World Trade Organisation. The key assumption is that income transfers to farmers are made on strictly defined environmental or social grounds and that increasing transparency brings with it strong pressure to justify any payments that are made in terms of the public goods produced. Policy is still on a voluntary basis with some farmers choosing to enrol land into the decoupled environmental schemes now widely on offer, or producing at world market prices. Such changes would be signalled during the forthcoming WTO negotiations, possibly with agreement in 2002/3 and followed by further CAP reform and implementation of decoupling over 5 - 10 years

Scenario 3: Rural Diversification - enhanced rural development policy with positive planning

This scenario assumes that rural land use policy is driven less by further changes in agricultural policy and more by greater emphasis being given to EU rural development policy. This policy is taken to imply the empowerment of local groups in line with the principle of subsidiarity and in accordance with recent community pilot initiatives embodying processes of community-led rural development (i.e. LEADER). The defining principle is one of local control of resources and land use policy, within a broad enabling framework of national and EU policies. Beside this, it is assumed that central governments issue planning guidance which gives greater priority to the development of the rural economy and less to countryside preservation. Such a scenario provides an alternative to the agricultural-policy-led scenarios which have been criticised as relics of agricultural fundamentalism, at a time when the importance of agriculture to the rural economy has diminished. It is assumed that this proceeds in the context of a partially decoupled CAP, as outlined in Scenario 1 (the current trend scenario). In this scenario it is assumed that both national governments and the EU are prepared to cede much more power to local or regional representative bodies. This is not likely to happen until a minimum of 5-10 years have elapsed and could vary greatly across Europe.

- **CLIMATE SCENARIOS**

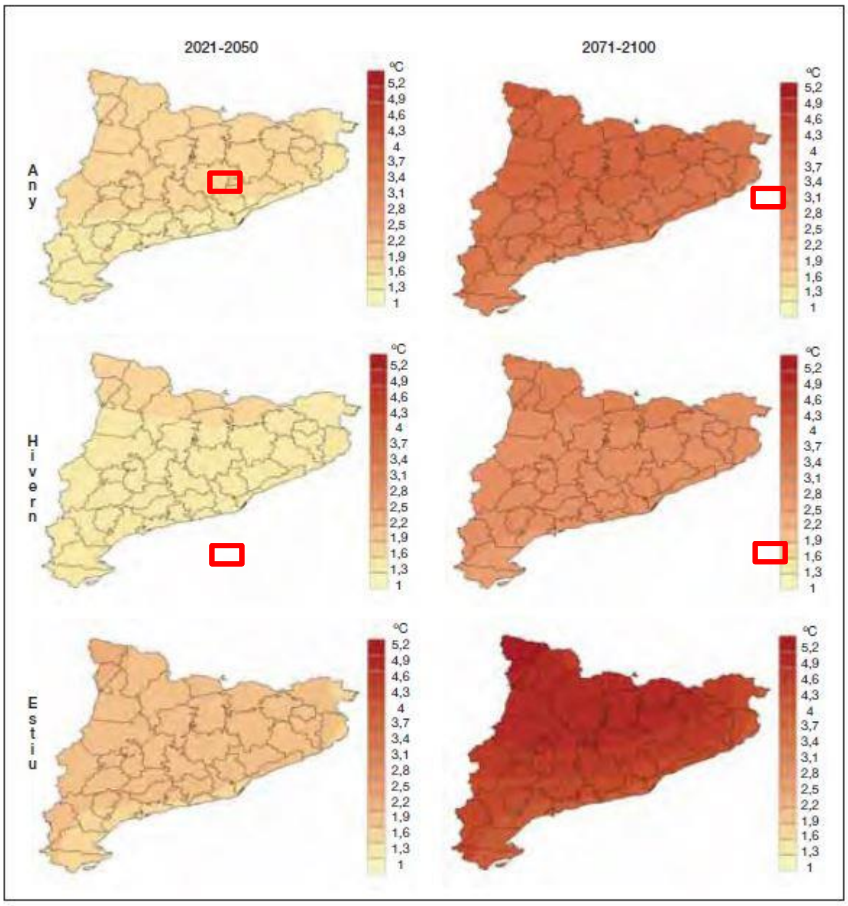


Figure 2.6: Increases in temperature (° C) annual (top), winter (middle) and summer (bottom) in Catalonia from the selected project ENSEMBLES simulations at 25 km resolution for the A1B emissions scenario and for the periods 2021-2050 (left) and 2071-2100 (right). Reference period 1971-2000.

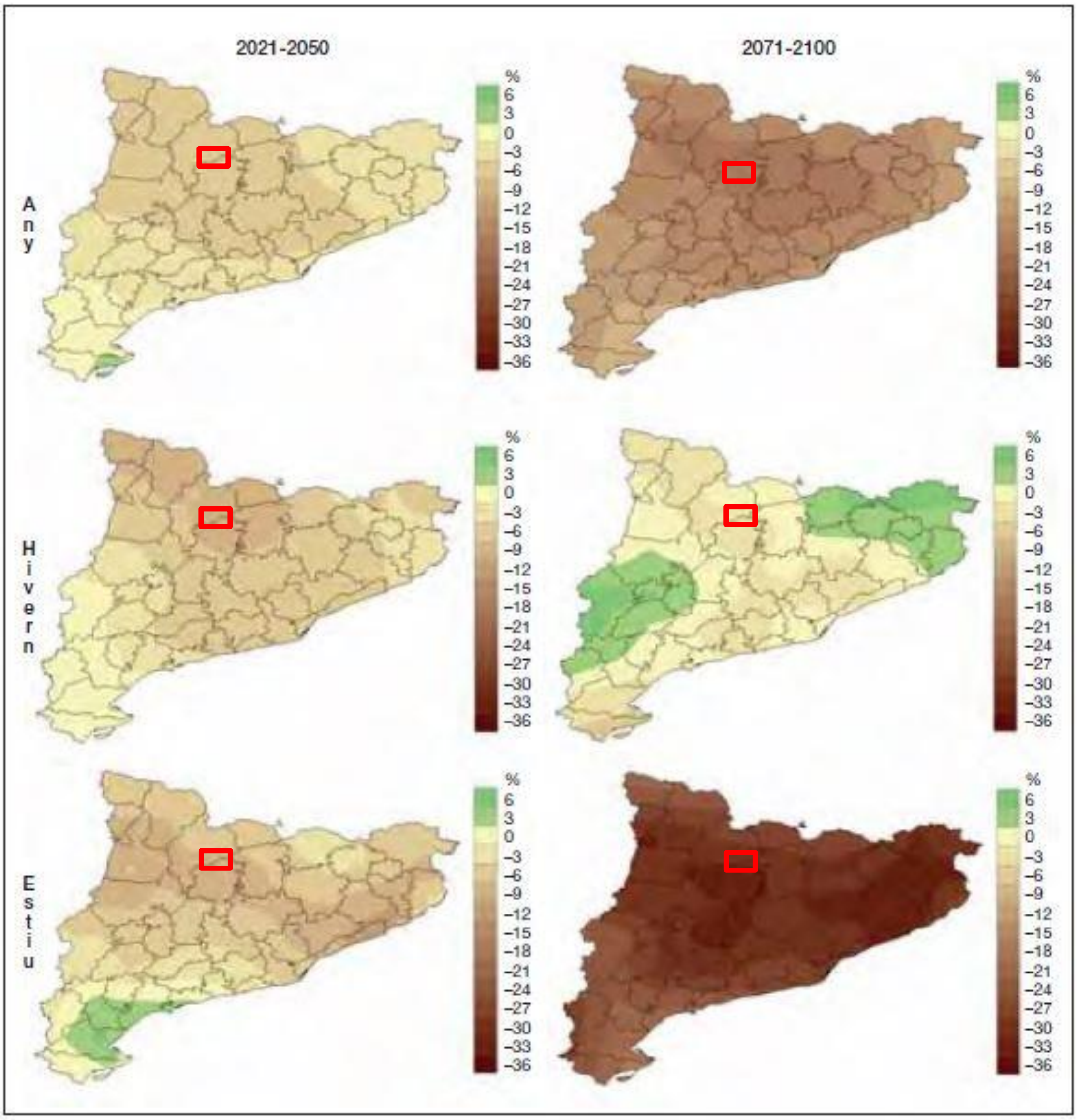


Figure **2.7** Changes in precipitation (%) per annum (above), winter (middle) and summer (bottom) in Catalonia from the simulations selected project ENSEMBLES 25 km resolution for the A1B emissions scenario and for the periods 2021-2050 (left) and 2071-2100 (right). Reference period 1971-2000.

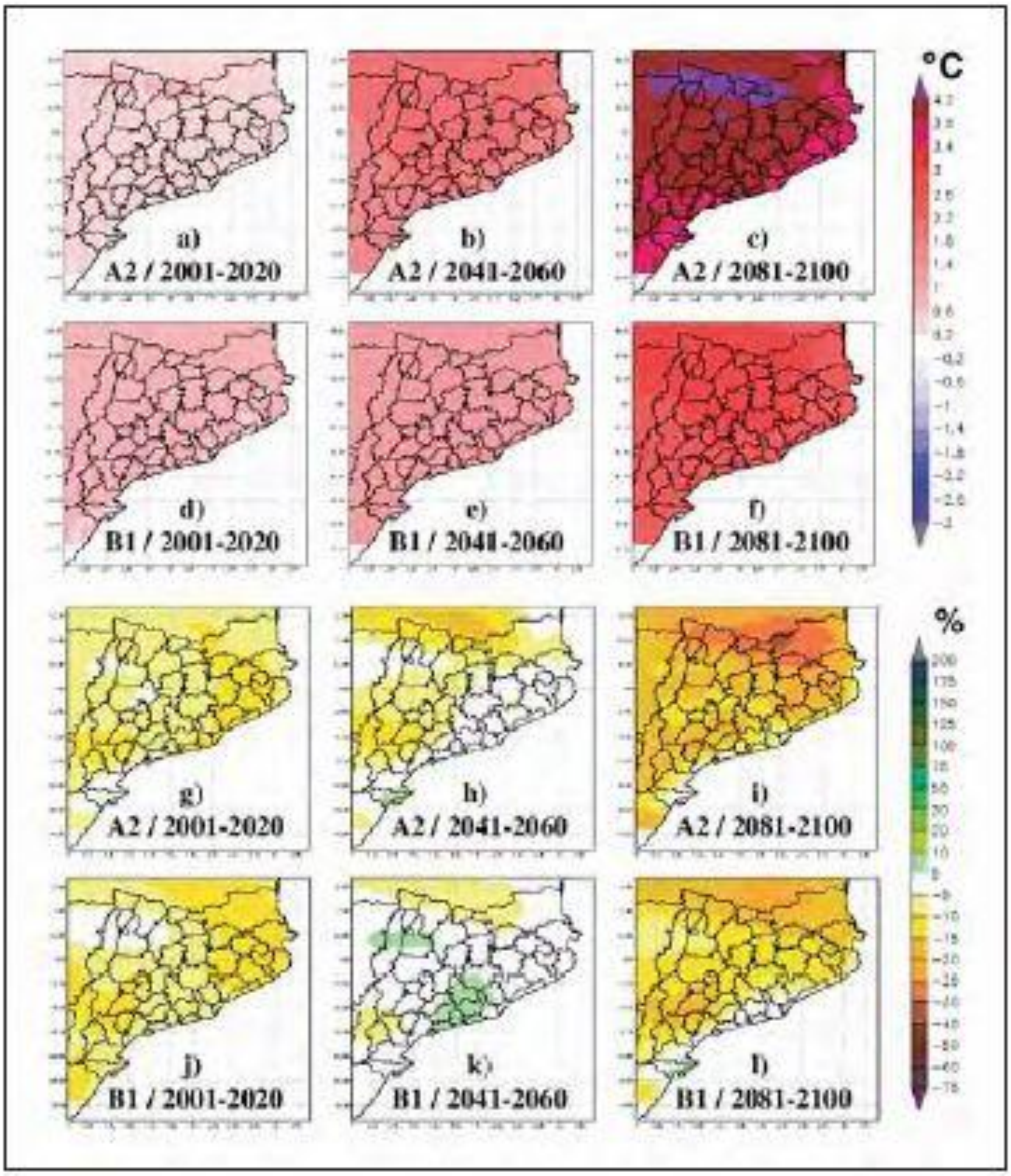


Figure 2.8: Maps camps temperature variation (sections af) and precipitation (gl sections) annual averages, obtained from the simulation with regionalized MM5 15 km (MM5 + ERA-40) for emission scenarios A2 and B1 and for the periods 2001-2020, 2041-2060 and 2081-2100. Reference period 1971-2000.

WP410 Reporting and dissemination of results

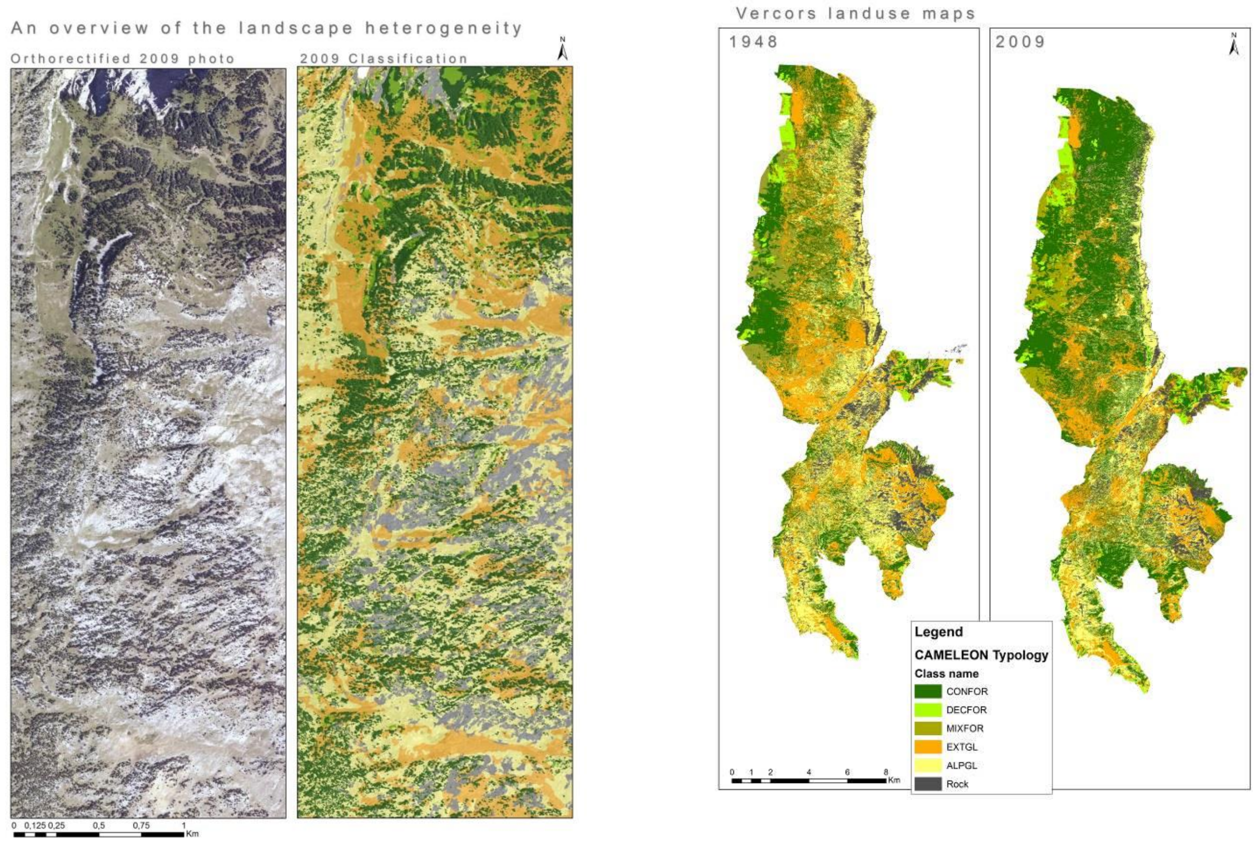
The dissemination of results will be done by the way of a set of scientific papers in preparation and a meeting to present a synthesis of the main project results with local stakeholders (in particular those who participated to the definition of future land use scenarios but also to a broader local community) that will be organized after the end of the project in autumn in the respective regions of the tree sites

3. Results

Land cover change

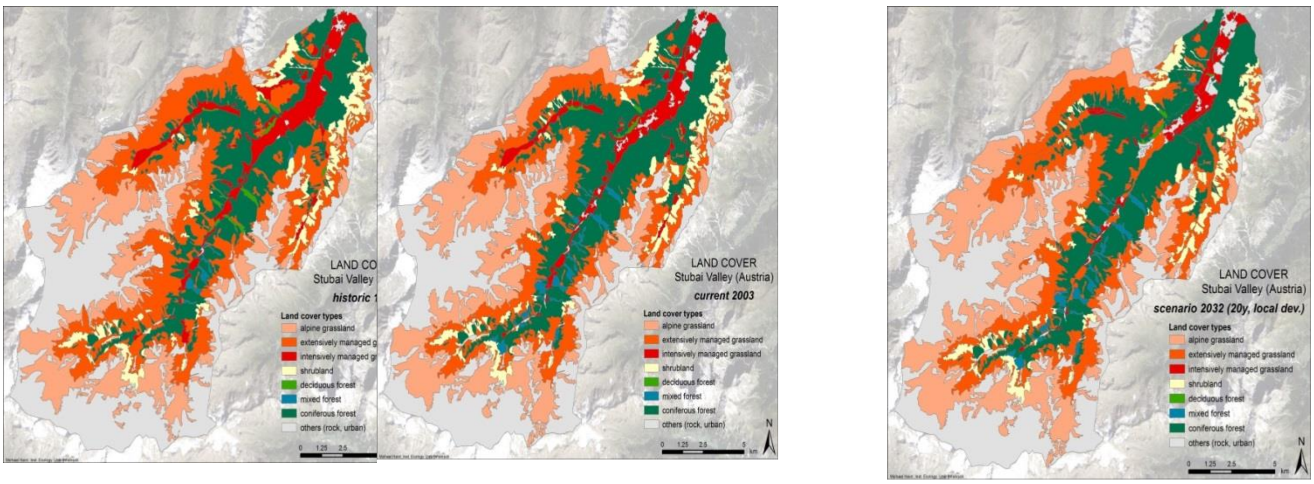
The figure 3.1a shows the result of image segmentation and hierarchical classification based on 2009 aerial photographs for part of the Vercors site. Land-cover maps are computed following three steps: (i) image segmentation based on spectral similarities of the pixels and size, compactness and shape of the objects; (ii) a supervised classification using nearest-neighbor algorithm and (iii) refined classification based on membership functions derived from ancillary thematic data (habitat map). The method has proven excellent reliability. The fine scale resolution outputs are aggregated over 1km gridcell to provide fraction of each vegetation unit. The figure 3.1b compares the results of classification for 1948 and 2009. The work has required the orthorectification, mosaicking and image processing of nearly 70 scanned photographs per date. The figure illustrate also that, even if for this study and especially for modeling purpose, land cover map was described as fraction of vegetation in 1km grid cells, original data is available at higher resolution.

Figure 3.2 shows an example of land cover for Stubai estimated for different period.
Figure 3.2a shows land cover for 1954, Figure 3.2b for 2003 and Figure 3.2c the projected land cover 2032 with local development scenario. Here again the reforestation during historical period is clearly visible whereas future scenario show mainly decrease of intensively managed grassland. In term of practical use, these maps will be very relevant not only in the frame of the project but also for stakeholders.



a/ b/

Figure 3.1 a) land cover classification from arial data for Vercors.in 2009 **b)** Results of land cover maps for 1948 and 2009.



a/ b/ c/

Figure 3.2: Land cover map for Stubai a/ in 1954 b/ in 2003 c/ projected for 2032 with the local development scenario

In Alinyà, the vegetation consists of alpine grasslands and subalpine coniferous forests in the highest levels, and cultivated areas at the bottom of the valley. This region is characterized by a high biodiversity as a result of its wide altitudinal gradient varying between 500 m and 2300 m (Bros et al. 2004). The mean annual temperature in Alinyà is 8.6°C while the mean annual precipitation is approximately 900 mm. The most dominant coniferous forest species are *Pinus* *nigra ssp. salzmannii*, *Pinus sylvestris* and *Pinus uncinata*. As for shrubs, the most common ones are *Buxus sempervirens* and *Juniperus communis ssp.* Based on the map of habitats in Alinyà from literature and from the map of habitats in Catalonia with a scale of 1:50 000 acquired from "CERBIV-La Generalitat de Catalunya" (2006), a map of the vegetation cover was developed with a grid of 1 Km x 1 Km (Figure 3.3).

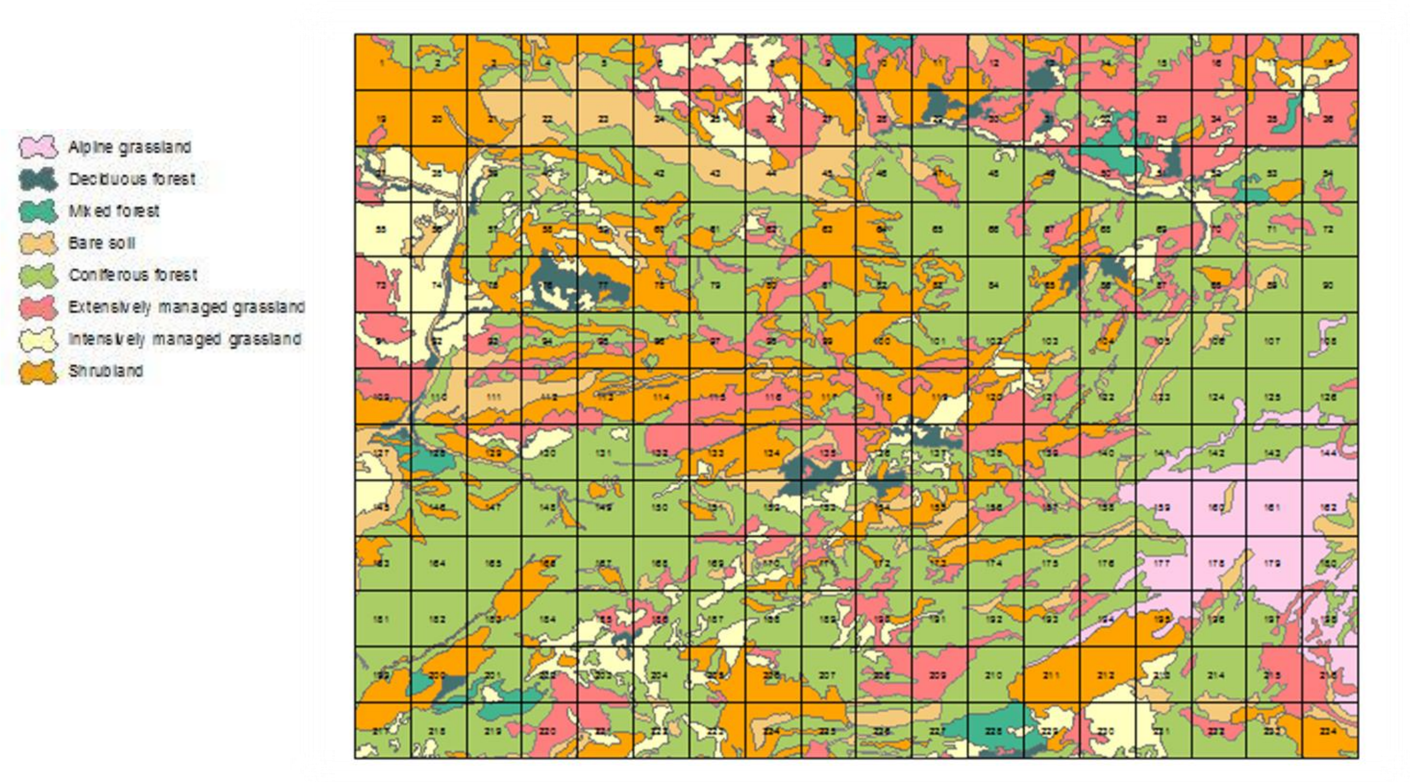


Fig.3.3 Land cover map of Alinyà valley (2006)

The figure 3.4 shows the resulting current land cover fractions projected on the 1km grid cell separating between grasses, forest and bare soil. There is no intensive (cut) grassland in Vercors plateau where the grasslands are only grazed. On the opposite there is almost no deciduous forest in Stubai largely dominated by conifers.

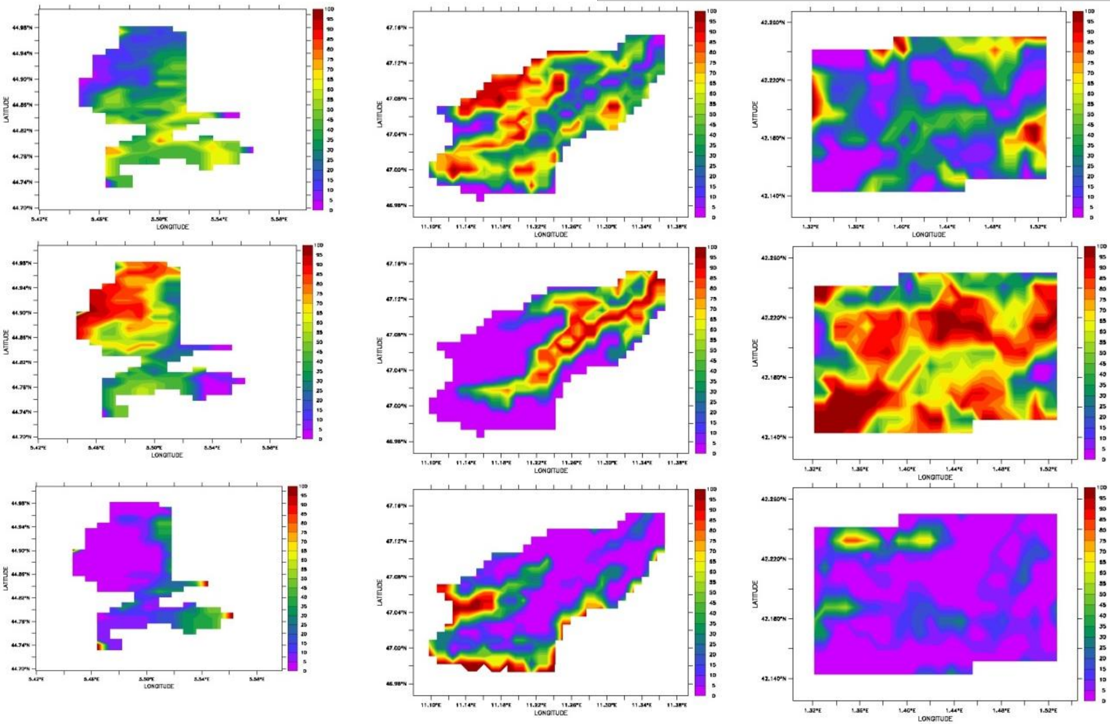


Figure 3.4 : current land cover fractions (%) of Grassland, forest and bare soil for the three sites

Figure 3.5 compares the evolution of land cover for Stubai and Vercors. For both sites three scenarios are considered for the future. The first one, (solid line) correspond to local scenario following the past trend. The second one (dots lines), global scenario is very similar for the first one. The last one (dashed lines) is the scenario of intensification of land use. For both sites the main land cover change is abandonment of grassland and then increase of forested area This trend is moderate for Stubai whereas it is more important for Vercors. in the Réserve Naturelle des Hauts Plateaux du Vercors, . Coniferous forest cover, composed primarily of *Pinus uncinata*, expanded by 80% from 40.9 to 73.8 km2 over the course of the study period. The extent of deciduous and mixed forest remained stable for all four dates at approximately 9 km2, or 6% of overall land covers. Extensive grassland receded by 39% from 45.2 km2 in 1948 to 27.7 km2 in 2009. Alpine grassland decreased by 40% from 39.0 in 1948 to 23.5 km2 in 2009. Slope and aspect classes did not have a significant effect on the rate of conifer expansion, while 300m elevation classes did. The rate of conifer expansion increased with altitude, suggesting that lower elevation zones were already mostly colonized by *Pinus uncinata* in 1948. The 90th percentile upper limit of *Pinus uncinata* distribution exhibited an altitudinal rise of 93m over the course of the study period. Increasing conifer cover appears to be correlated with rising air temperatures during the same period, although this relationship requires further testing. Despite a lack of detailed historical land use data, it seems highly likely that changes in land use practices in the RNHPV have been an important enabler of forest densification and expansion since 1948. Encroachment of coniferous forest into alpine grassland communities is important from a conservation perspective, as the extent of these diverse communities is rapidly shrinking.

For the future scenarios, the more conservative projected scenarios show the same trend in grassland abandonment. But more intensive scenarios indicate a reverting trend after 2020 especially for Vercors where grassland is supposed to recover is state of 1990 around 2040. As scenarios are projected only up to 2040, we considered a constant land cover after this date

Changes in vegetation composition (RNHPV), France, were investigated by classifying aerial imagery from 1948, 1978, 1993 and 2009

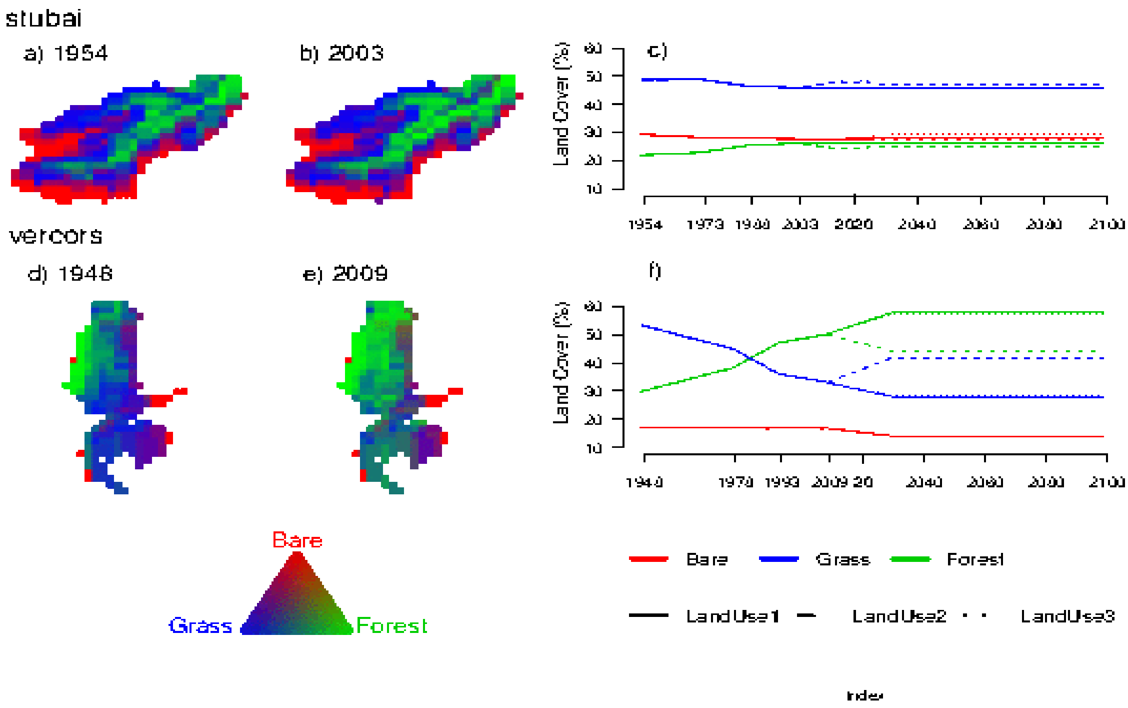


Figure 3.5: Evolution of land cover change for Stubai and Vercors for reconstructed history to projected scenarios. Green represents forest, Blue: grassland and red bare soil. Left figures represent the spatial distribution for the first date and for current situation. Right figure represent the spatially mean evolution of the percentage of each cover. The three land use scenarios are represented by solid, dashed and dotted lines.

Remotely-sensed vegetation dynamics

- **Maps of the median phenological parameters**

Figure 5, show the maps of the median values of the start of the growing season for Alinya, Stubai and Vercors derived either from SPOT-VGT NDVI S10 remote sensing products or ORCH-GM simulations. For Alinya, no ORCH-GM were available and only the SPOT-VGT derived estimates are displayed.

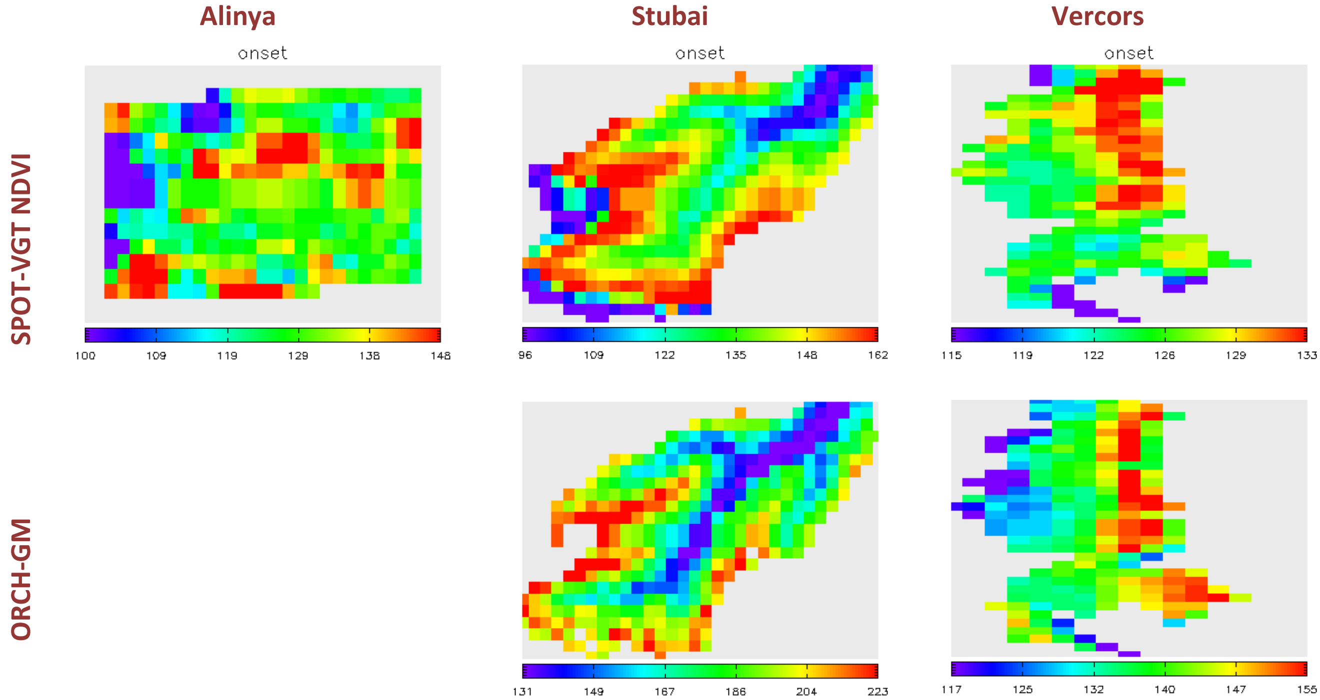


Figure 3.6: *maps of the median values of the start (onset) of the growing season over the 1999-2010 period derived from SPOT-VGT NDVI S10 (top) and ORCH-GM (bottom) for Alinya, Stubai, and Vercors.*

For the Stubai site, there is a clear correspondence between the phenological parameters derived both from SPOT-VGT and ORCH-GM data and the mean elevation at 1km. There is thus an altitudinal gradient of the leaf onset with earlier onset dates in the Stubai valley and later onset at higher altitudes (note that the low values obtained on the South West border of the area at the highest altitudes are related to bare soils and are note associated to any vegetation signal). Even though the absolute values differ between the SPOT-VGT and the ORCH-GM estimates (as a consequence of the estimation procedures as described earlier), there is a strong agreement between the two products with regard to the spatial patterns.

The agreement between SPOT-VGT and ORCH-GM derived parameters is a bit lower for the Vercors area. The median onset date seems to be more related to elevation in ORCH-GM derived products than in the SPOT-VGT one (earlier onset on the North West part of the area that exhibit lower elevation). Both products agree in the later onset dates on the Eastern part of the area, but ORCH-GM simulates later dates than SPOT-VGT in the South East, again in correlation with higher altitudes.

For Alinya, there is no obvious dependence of the phenological parameters retrieved from SPOT-VGT time series with elevation, apart for the low altitude area on the West part of the area where earlier onsets are estimated. There seems to be a stronger relationship with the vegetation type than for the other sites as for instance the later starts of the growing season are estimated for areas with dominant fraction of needleleaf evergreen trees.

- **Inter-annual anomalies of the starting date of the growing season**

The figures below present the maps of the onset anomaly estimated for each year between 1999 and 2010 for the three study area.

For Stubai and Vercors, there is generally an agreement in the year to year variation of the anomaly between the estimates derived from SPOT-VGT data and ORCH-GM simulations, with regard to the sign of the anomaly and its magnitude. For the Stubai area, ORCH-GM derived

products exhibit finer spatial structures, in relation to the altitudinal gradient, than the remotely sensed derived products. For Vercors, there is often a discontinuity of the anomaly spatial structure (change of sign) in the North West part of the area (for instance year 2001 for the two products), that is correlated with the elevation changes. This discontinuity varies with the year and is not always in phase between the two products.
The order of magnitude of the onset anomaly can be viewed as an indicator of the sensibility of the ecosystems to climate. Thus, the Alinya site seems to be the most responsive to inter-annual changes in meteorological forcing (temperature) whereas Stubai and Vercors show lower and similar sensitivities. The differences between the sites also traduces differences in the dominant climatic regimes, Alinya being more influenced by Mediterranean climate while Stubai and Vercors have more similar meteorological conditions, as outlined by Figure , that presents the inter-annual variations of the monthly mean temperatures estimated over the whole of the Stubai and Vercors areas and on the 1999-2010 period.
Years 2002, 2003 and 2007, show negative onset anomalies which are compatible with the positive anomalies of temperature observed for (most) of the first months of the year in the latter figure. Note that a similar negative anomaly is observed for Alinya in 2003, but not in 2007 where it is mostly positive. Conversely, years 2004 and 2006, are colder than the mean and a delay of the start of the growing season is observed in Stubai, both from SPOT-VGT data and ORCH-GM simulations. For Vercors however, whereas ORCH-GM simulates a similar behavior, SPOT-VGT derived onset rather indicates a later start of the growing season. Thus, a straight relationship between the inter-annual variations of the monthly mean temperature and the onset anomaly is less clear for other years. For instance, whereas year 2001 is warmer than the mean over the 12 years in January, February, March and May, the derived onset dates generally indicate later leaf unfolding in Stubai, but an earlier one in Vercors. The monthly temperatures in 2005 are generally lower than the mean. Nevertheless, whereas ORCH-GM mostly simulates a delay of the start of the growing season, in agreement with these monthly temperature anomalies, SPOT-VGT derived onset anomalies show contrasting results with mostly a earlier onset date in Stubai and positive as well as negative onset anomalies in Vercors.

The origin of the differences between SPOT-VGT and ORCH-GM derived products is not clear (some years present opposite anomalies between the SPOT-VGT and ORCH-GM estimates depending on the site: 1999, 2005, 2008 and 2010 for Stubai; 1999, 2003, 2004, 2008, for Vercors). Given the spatial extent of the differences, this is unlikely attributed to noise in the SPOT-VGT products, but rather highlights that the some of the model processes that simulate the meteorological control on leaf phenology differ from reality in these mountain ecosystems.

Stubai **Vercors**

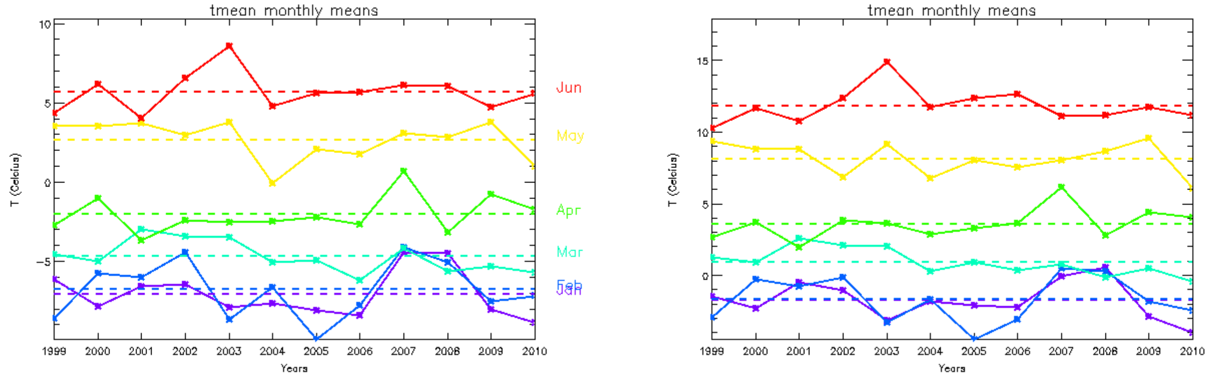


Figure 3.7: *Inter—annual variations of the monthly mean temperatures for the Stubai and Vercors area for the months of January to June.*

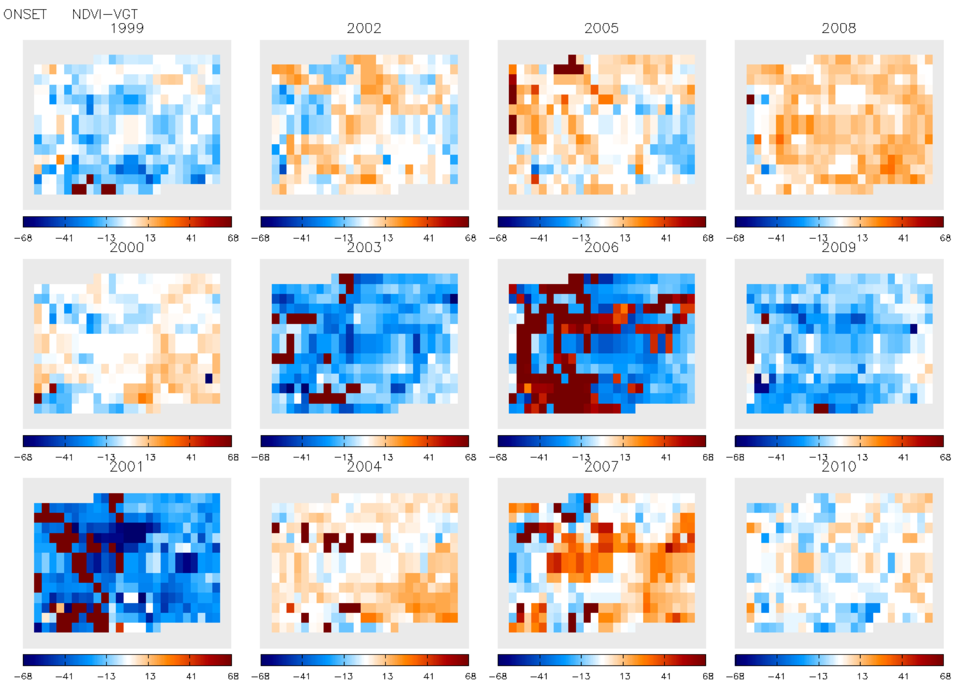


Figure 3.8: *Alinya: year to year variation of the anomaly of the starting date of the growing season estimated from SPOT-VGT NDVI S10 products over the 1999-2010 period.*

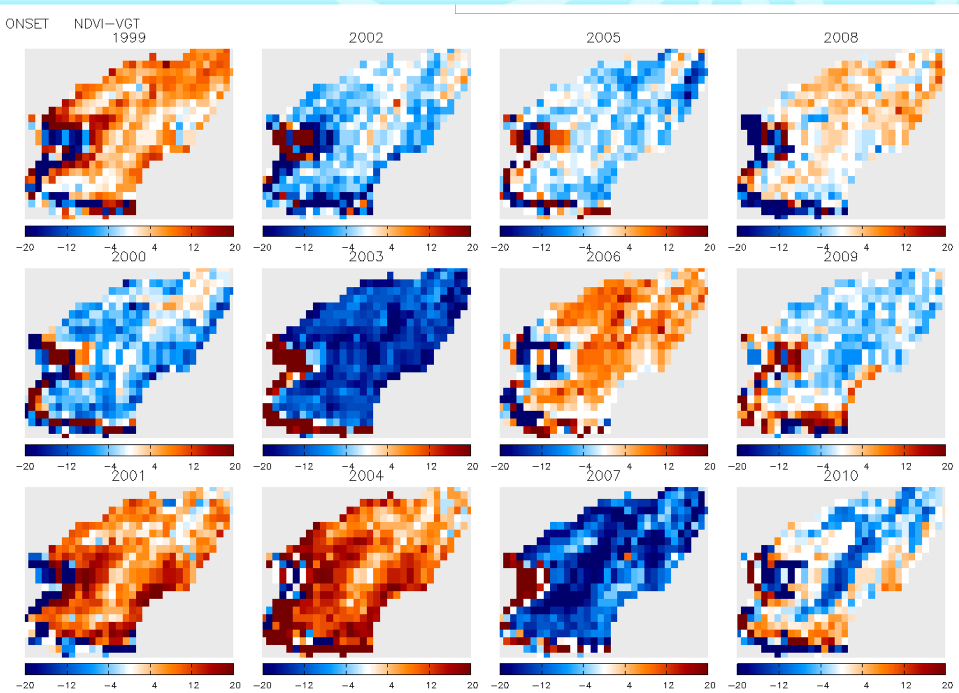


Figure 3.9: *Stubai: year to year variation of the anomaly of the starting date of the growing season estimated from SPOT-VGT NDVI S10 products over the 1999-2010 period.*

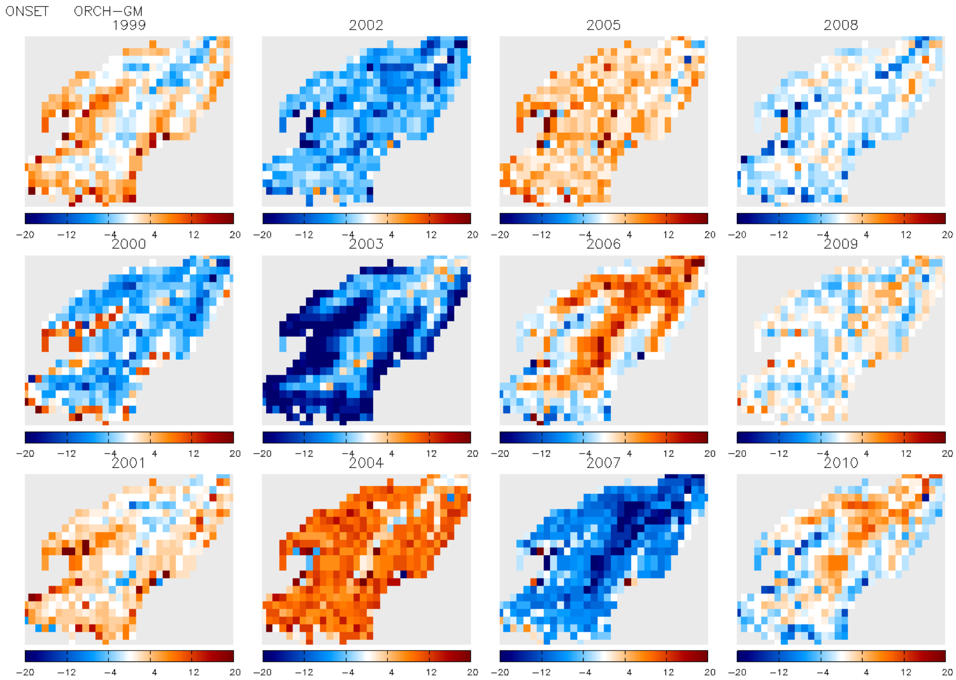


Figure 3.10: *Stubai: year to year variation of the anomaly of the starting date of the growing season estimated from ORCH-GM simulations over the 1999-2010 period.*

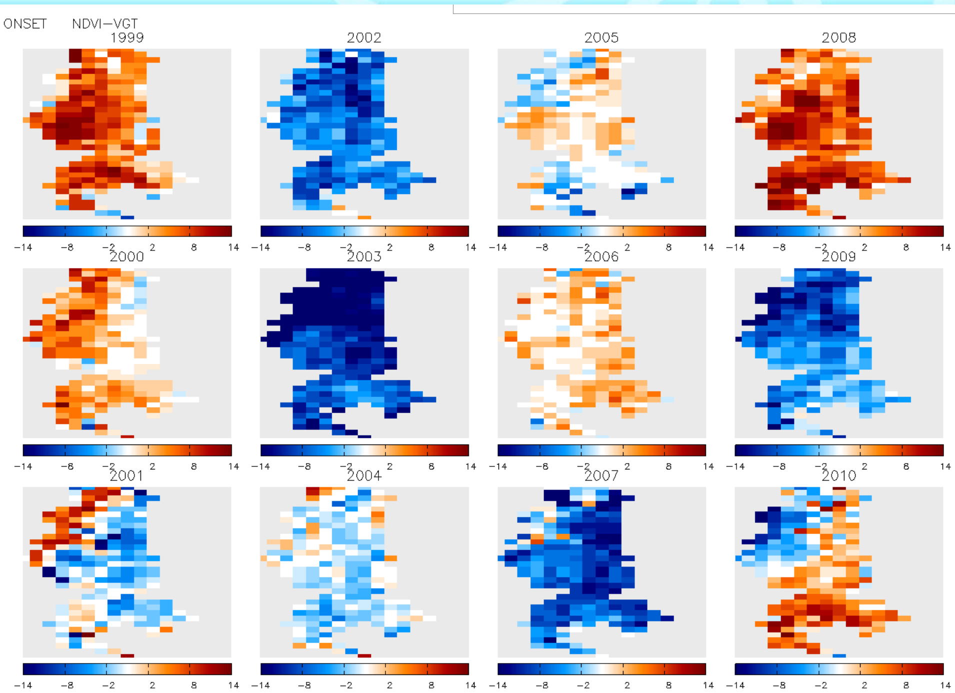


Figure 3.11: *Vercors: year to year variation of the anomaly of the starting date of the growing season estimated from SPOT-VGT NDVI S10 products over the 1999-2010 period.*

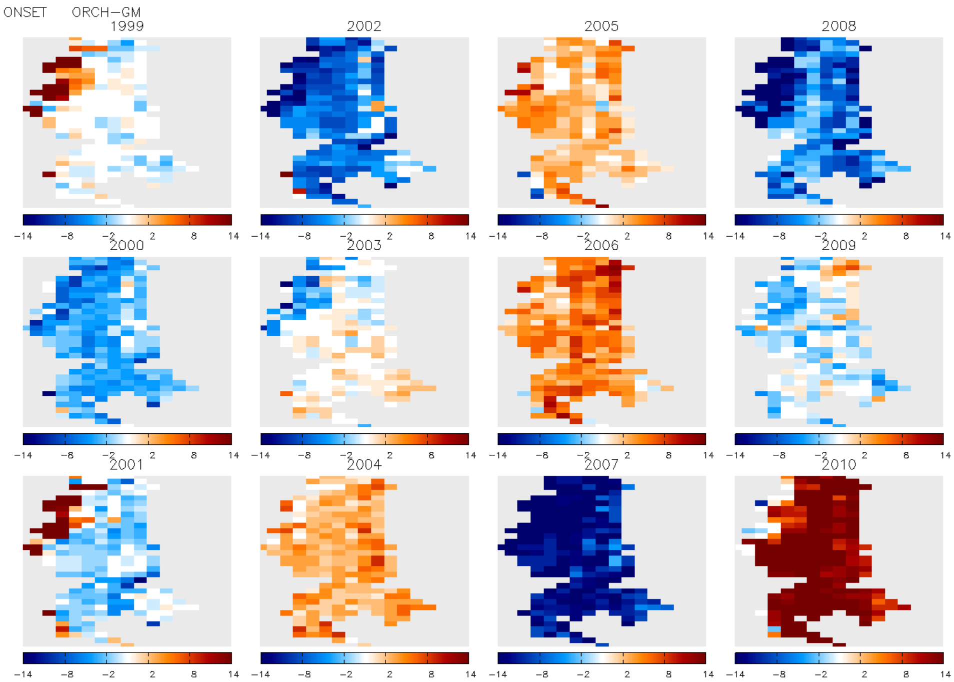


Figure 3.12: *Vercors: year to year variation of the anomaly of the starting date of the growing season estimated from ORCH-GM simulations over the 1999-2010 period.*

Calibration evaluation and improvement of ORCHIDEE

Optimisation on ORCHIDEE model parameters through data assimilation

The improvement of the global ORCHIDEE vegetation model has been undertaken by two parallel approaches:

- optimization of few phenological parameters from the assimilation of 12 years of SPOT-VGT NDVI remote sensing data for the main vegetation types. This work has been undertaken for the Stubai and Vercors site.
- optimization of an increased number of model parameters, controlling photosynthesis, respiration, phenology, soil water stresses and energy balance, processes, from assimilation of *in situ* flux measurements at the grassland Alinya and Stubai sites.

The version of ORCHIDEE (ORCH-STD) used in these studies is different than the ORCHIDEE version used for studying the impact of climate and land use scenarios (ORCH-GM). The main difference concerns the phenology module that has been improved for grasslands in ORCH-GM (also accounting for animal or management module), whereas it directly derives from Botta (2000) in ORCH-STD. Over the study sites, the latter module simulates incorrect growing season length for natural alpine grasslands in particular.

1. Overview of the assimilation system

The assimilation procedure relies on a 4D-Var assimilation system that minimizes a misfit function misfit function *J(**x**)* that measures the mismatch between 1) a set of observations ***y*** and corresponding model outputs ***H.x***, and 2) the values *x* of the parameters (to optimize) and some prior information on them $\boldsymbol{x_b}$, weighted by the prior error covariance matrices on observations ***R*** and parameters ***B*** with the assumption of Gaussian errors (Tarantola, 1987):

$$J(\mathbf{x}) = \frac{1}{2}(\mathbf{H}.\mathbf{x}-\mathbf{y})^t\,\mathbf{R}^{-1}(\mathbf{H}.\mathbf{x}-\mathbf{y}) + \frac{1}{2}(\mathbf{x}-\mathbf{x_b})^t\,\mathbf{B}^{-1}(\mathbf{x}-\mathbf{x_b}) \qquad \textit{Eq. 1}$$

The determination of the optimal set of parameters that minimizes *J(**x**)* is performed by successive calls to the L-BFGS-B algorithm (Zhu *et al.*, 1995), specifically dedicated to solve large nonlinear optimization problems subject to simple bounds on the variables.

2. Assimilation of Earth Observation data to optimise the leaf phenology simulated by ORCHIDEE

The ***y*** observation considered in Eq. 1 consists in twelve years of SPOT NDVI (S10) time series (ten days resolution) from 1999 to 2010 for an ensemble of selected pixels.
For each site and each Vegetation Type (VT) among the seven ones considered, we have selected four high quality pixels fulfilling several constraints. First the grid cells have to be representative of the considered VT and thus exhibit a high VT coverage, as well as high coverage of the corresponding ORCHIDEE PFT. Second the NDVI signal should not be too noisy and thus need to have a large number of observations. For the selection, we have favoured the pixels which already showed a high correlation with ORCH-STD LAI simulations. The configuration of the assimilation system permits a multi-site optimisation where the parameters are optimised for all pixels (and hence all PFTs) together.
For Stubai, we also have selected 3 pixels for the Extensive and Intensive Grasslands vegetation types, in addition to the natural vegetation types.
The modeled fAPAR values (***H.x*** in Eq. 1) are matched to NDVI satellite products, the two quantities being strongly linearly related. fAPAR simulated by ORCHIDEE is a function of the

prognostic LAI derived by the model using a simple Beer-Lambert law (using a constant extinction coefficient of light within the canopy): fAPAR = 1-exp(-0.5xLAI).

In the standard version of ORCH-STD, the start of senescence is controlled only by the ages of the leaves for C3 grasses whereas it is also driven by temperature for other plant types. A preliminary analysis has proved the importance of adding this dependence of leaf senescence to temperature for alpine grasslands which significantly improves the model agreement to SPOT-NDVI data, especially for the Stubai site. We optimize four parameters that primarily control the seasonal evolution of the modeled leaf Area Index (LAI), and hence of fAPAR. The respective roles of each parameter in the control of the leaf phenology are described below:

- *Klaihappy*: fraction of carbohydrate reserve used for leaf growth;
- *Kpheno_crit*: scalar of temperature threshold;
- *Leafagecrit*: critical leaf age;
- *Senescence_temp_c*: temperature threshold for senescence.

For Stubai and Vercors, the simulated fAPAR agrees relatively well with the SPOT data, the model-data fit being generally improved after assimilation for all PFTs, the improvement being significantly higher for grasslands than for the other plant functional types. The model-data agreement is however lower for Alinya, and the assimilation only slightly improves it. For the broadleaf and needleleaf tree species, the prior ORCH-STD model already captures reasonably well the phasing and length of the growing season, and its inter-annual variation, for Stubai and Vercors as compared to the NDVI time series. There is therefore only little room for improvement by the data assimilation, given the model-data error. The Deciduous and Evergreen tree species show a slight extent of the growing season length by a later start of senescence after assimilation. For the grasslands however, the growing season simulated with the default ORCH-STD parameters is much longer than what is seen in SPOT-NDVI signal. For Stubai and Vercors, the start of the growing season simulated by the prior model is already well in phase with the observations and thus the parameter optimization leads to a strong reduction of the length of the growing season mainly by simulating an earlier leaf senescence (Figure 8). As a result, the Root Mean Square Error of model data fit is reduced by about a factor 2 for the two sites. The optimized model also reproduces well the inter-annual variations of the growing season length (with respect to SPOT NDVI), in particular the shorter growing season length observed in 2003 due to the summer heat wave that impacted Western Europe. For Alinya however, the prior model simulates simultaneously much earlier start and end of the growing season than what is monitored by SPOT NDVI. The assimilation fails to reproduce the seasonality of the SPOT NDVI data even though a slight improvement of the model-data fit is obtained.

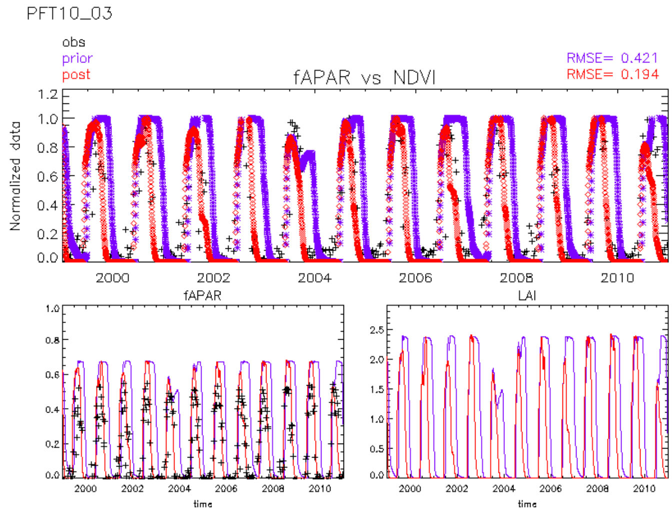
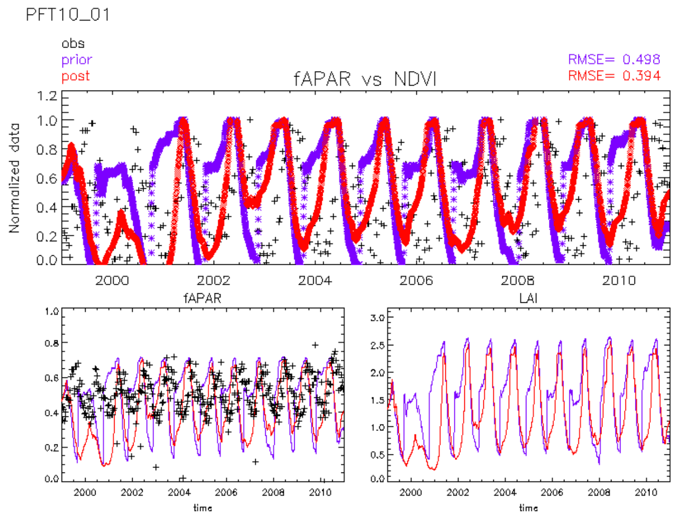
	**Stubai** lat= 47.089268° lon= 11.160732° bare soil = 6% PFT10 = 94%
	**Alinya** lat=42.25° lon=1.5178902° bare soil = 2% PFT06=2% PFT07=2% PFT08=5% PFT10=89%

Figure 3.13: *Some examples of the model data fit before and after assimilation of SPOT-VGT NDVI time series for grassland pixels in Stubai and Alinya. The upper insets show the normalised time series of SPOT NDVI (black) compared to the prior (blue) and posterior (red) ORCHIDEE simulations; the bottom left insets present the same NDVI and fAPAR time series without normalisation; the bottom right insets present the corresponding ORCHIDEE LAI simulations. The Root Mean Square Error (RMSE) of model fit to the data is indicated.*

Table 1 provides the value of the phenological parameters prior and posterior to the assimilation. One can notice that the optimized values for Alinya depart strongly from those retrieved for Stubai and Vercors, that are in fair agreement. This reinforces the previous observations about the similarities in vegetation species in Vercors and Stubai and their dissimilarities with Alinya. For the Stubai site, a similar assimilation study conducted on pixels corresponding mainly to managed ecosystems – Extensive and Intensive grasslands – has provided very similar results to those obtained for the natural alpine grasslands.

Table 1: Parameter values, prior and posterior to the assimilation, for the PFTs considered for Stubai, Vercors and Alinya. Bold values indicate when a optimized value hits a bound of the parameter range of variation.

Parameters	ORCHIDEE Plant Functional Types	prior values	posterior values			
			Stubai	Vercors	mean Stubai and Vercors	Alinya
Kpheno_crit	Dec. Broadleaf Forest	1.0	-	**0.7**	**0.7**	1.77
	Coniferous Evergreen Forest	1.0	1.0	1.0	1.0	1.0
	Dec. Coniferous Forest	1.0	0.7	-	**0.7**	1.8
	Grassland	1.0	0.81	0.79	0.8	2.84
Senescence_temp_c	Dec. Broadleaf Forest	12.0	-	7.8	7.8	21.41
	Coniferous Evergreen Forest	-	-	-	-	-
	Dec. Coniferous Forest	7.0	5.16	-	5.16	10.26
	Grassland	-1.375	8.15	8.77	8.46	-1.375
Leafagecrit	Dec. Broadleaf Forest	180.0	-	208.2	208.2	**90.0**
	Coniferous Evergreen Forest	910.0	984.2	949.1	966.65	**810.**
	Dec. Coniferous Forest	180.0	216.2	-	216.2	**75.0**
	Grassland	120.0	64.3	82.2	73.25	307.31
Klaihappy	Dec. Broadleaf Forest	0.5	-	0.56	0.56	**0.35**
	Coniferous Evergreen Forest	0.5	0.5	0.5	0.5	0.5
	Dec. Coniferous Forest	0.5	0.61	-	0.61	**0.35**
	Grassland	0.5	0.4	0.4	0.4	0.36

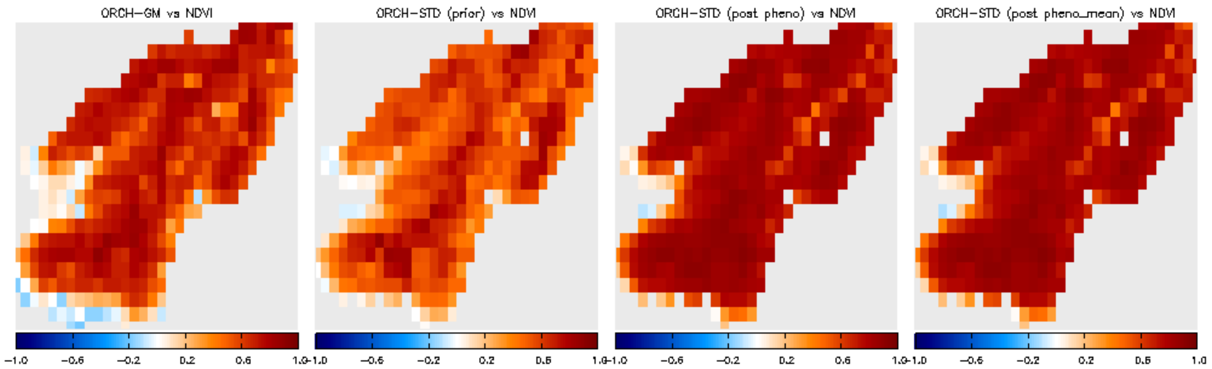
In order to evaluate the model improvement following the optimization of the phenological parameters, we have calculated, for Stubai and Vercors, the correlation between the SPOT NDVI data over the 1999-2010 period and the corresponding fAPAR simulations from:

- ORCH-GM;
- ORCH-STD with the standard parameters (ORCH-STD prior);
- ORCH-STD after optimization, accounting for the parameter set retrieved independently at each site (ORCH-STD post pheno);

- ORCH-STD after optimization, accounting for the average of the parameters obtained at Stubai and Vercors (ORCH-STD post mean).

The figure below shows strong and positive correlation coefficients of the ORCH-GM model for both sites for most of the pixels, the correlation being significantly higher for Vercors than for Stubai. For Stubai, few pixel show very poor correlation values, mainly on the South West border of the area; these pixels are dominated by bare soil. The fAPAR simulations derived from ORCH-STD standard parameterization provides poorer agreement with SPOT NDVI time series for almost all pixels, the decrease of the correlation being proportional to the fraction of grassland PFT in the pixel considered. The improvement of the model-data correlation following the model optimization is evident. Interestingly, the use of the mean set of optimized phonological parameters (ORCH-STD post mean) produces correlation maps with about as high coefficient values than when the assimilation is performed for each site specifically. This tends to indicate that there is a generic set of phenological parameters that allows reproducing reasonably well the vegetation seasonal cycle of the alpine vegetation types considered in regions with climatic conditions similar to Stubai or Vercors

Stubai



Vercors

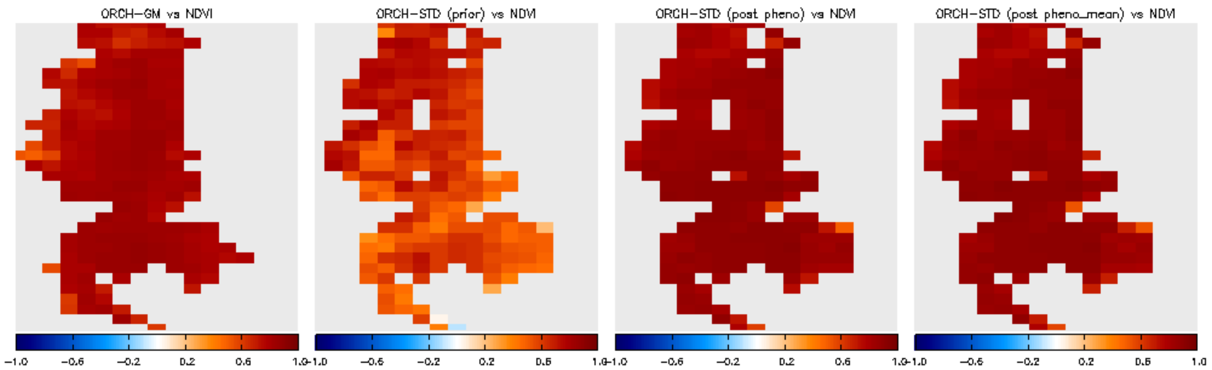
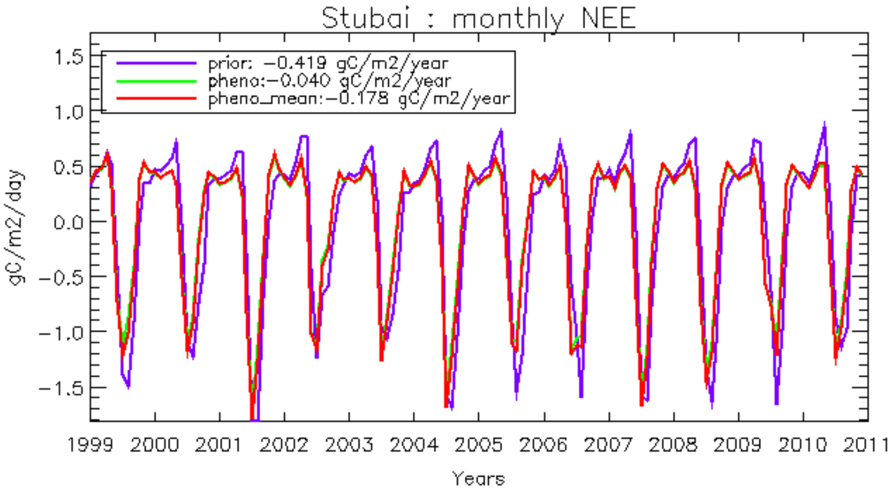


Figure 3.14: *Correlation maps between SPOT NDVI S10 data from 1999 to 2010 and 1) ORCH-GM, 2) ORCH-STD with standard parameters, 3) ORCH-STD with the phenological parameters optimised for Stubai, 4) ORCH-STD with the mean phenological parameter set, for Stubai and Vercors.*

The Figure below presents the temporal variations of the simulated monthly means of the net CO2 flux over the whole of the Stubai and Vercors areas, with the prior ORCH-STD model, and the optimized versions using either the optimized phenological parameters based on the site specific assimilations or using the means. The magnitude of the simulated NEE annual cycle is smaller in Vercors than in Stubai (combination of a lower winter respiration and a carbon uptake lower in summer by about 2.5), with a higher inter-annual variability.

The simulations based on the optimized parameter sets slightly change the annual balances. For the two sites, the optimized model simulates lower annual carbon uptakes. While they remains close to equilibrium (the assimilation does not impact directly the soil carbon pools), the posterior simulations for Vercors, changing only the model phenological parameters, lead to a change from an annual sink to a annual source of carbon for Vercors. This result has to be interpreted with caution given that it is also a direct consequence of the model assimilation setup where the spin-up of the model is made only once, prior to the assimilation, and where there is no dataset constraining the soil carbon pools. For Stubai, the monthly time series depicts the shortening of the growing season length in the optimized simulations. The magnitude of the NEE annual cycle is generally reduced in the posterior simulations.



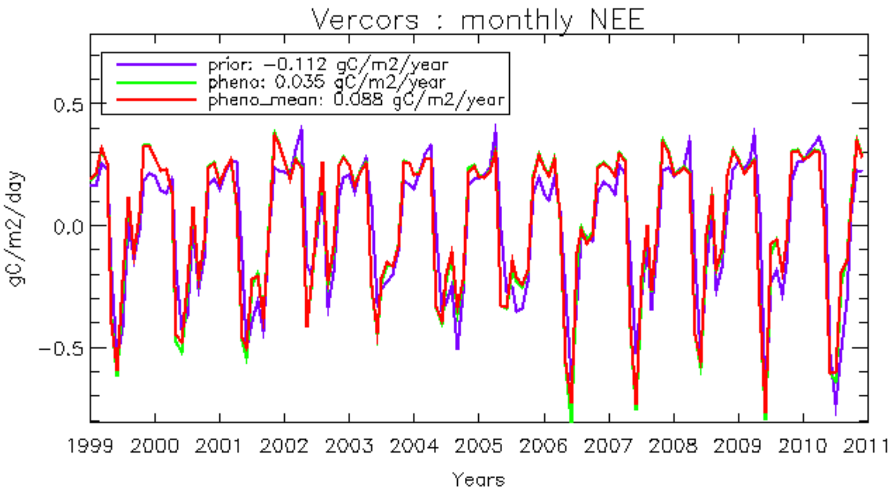


Figure 3.15: *Temporal variations of the NEE monthly means over the whole of the Stubai and Vercors areas simulated with the ORCH-STD model prior (blue), and posterior to the assimilation of SPOT NDVI products for the site specific cases only (green) or combining Stubai and Vercors optimised phenological parameters (red). The mean annual balance is indicated for each simulation.*

3. Optimization of ORCHIDEE parameterization through data assimilation of *in situ* flux measurements

The model data fusion presented here uses jointly daily means of *in situ* flux measurements of net CO_2 (NEE) and latent heat (Qle) fluxes performed at the Stubai and Alinya sites over managed grassland. The assimilation is undertaken with the ORCH-STD model that does not account for any animal or management module. In particular, the harvests performed at the Stubai site cannot be captured by the standard parameterization of the model, given the sole meteorological forcing. An overcorrection of the ORCH-STD parameters is therefore expected. The objective of this assimilation study is to evaluate if a simple change in the model parameterization (without adding any specific management module) allows representing the seasonal variation of exchange of mass and energy for managed pastures, and to which extent.

In addition to the phenological parameters presented in the above study, we have selected, among all ORCHIDEE parameters, the most significant ones which primarily drive NEE and LE variations from synoptic to seasonal time-scales (Santaren et al., 2013), by controlling photosynthesis, respiration, phenology, soil water stresses and energy balance, processes. For Stubai however, we have taken into account a temporal variation of the observation error in order to not constrain too much the model to fit the measurements after the harvest; this is undertaken by increasing the value of the *a priori* error after the harvest, typically between days of year 140 and 255.

The comparison of the model-data fit prior and posterior to the assimilations, with respect to the seasonal cycle of the various fluxes measured *in situ* (NEE and Qle plus ancillary observations of sensible heat flux – Qh, gross primary productivity – GPP, total ecosystem respiration - TER) is presented in the figures below for Stubai and Alinya. The model data fit is also evaluated with respect to ORCH-GM, which specific animal and management modules. In general, ORCH-GM provides better fit to the various datasets than the *a priori* ORCH-STD. The data assimilation however allows improving significantly the simulation of the flux seasonal cycle as indicated by the decrease of the RMSE of fit, leading to generally a better model-data agreement for the optimized ORCH-STD. The model improvement is even more important for Alinya, considering the higher model-data misfit of the prior simulations. For NEE, the assimilation allow representing the phasing and length of the seasonal cycle in better agreement with the observations. For Stubai, the harvests lead to strong NEE peaks in summer due jointly to the decrease in the carbon uptake and an increase in the ecosystem respiration. The ORCH-STD simulations are smoother and not able to reproduce these events, as expected as it cannot reproduce the rapid changes in the dynamics of LAI as the ORCH-GM does. During the harvest periods, the ORCH-GM model agrees well with the *in* situ *data*. Both ORCH-STD and ORCH-GM simulate high carbon before the start of the growing season, in contradiction with the observations. This is most likely because the ORCHIDEE models overestimate snow sublimation.

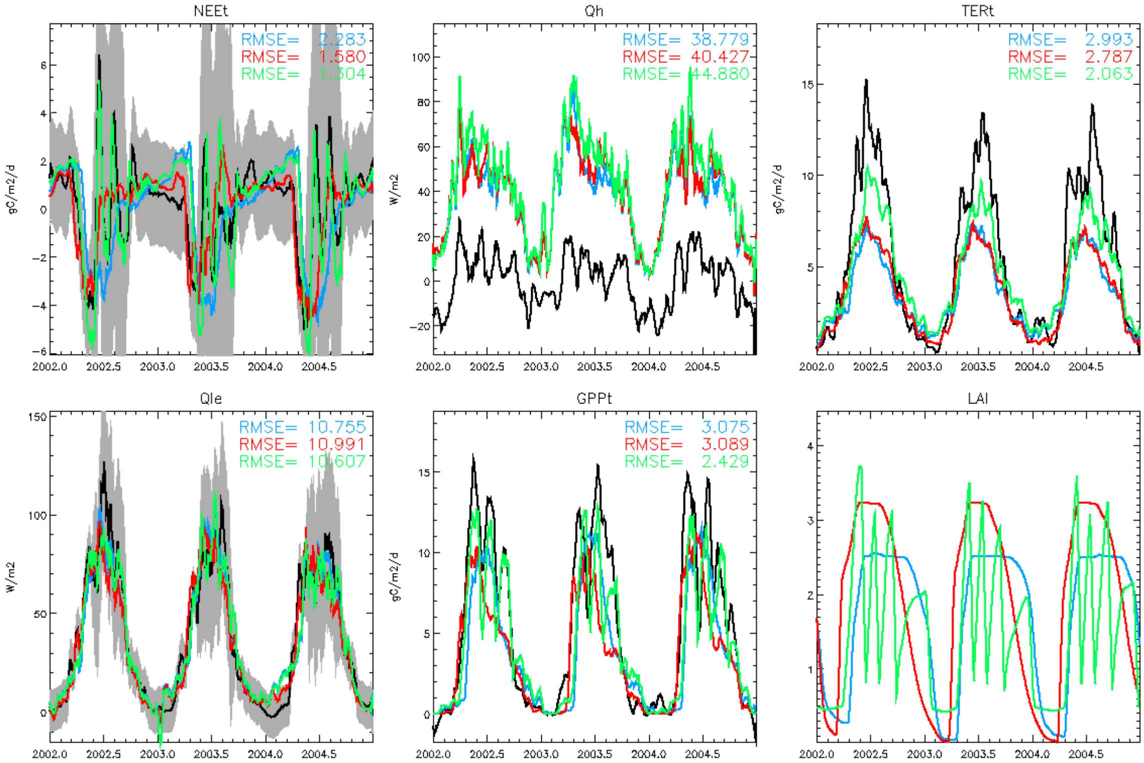


Figure 3.16: *Stubai: comparison of the fit of the ORCHIDEE simulations to the various in situ measurements (daily means) considering the assimilation of NEE and Qle flux data .The observations are shown in black, the prior ORCH-STD model is shown in blue, the optimized ORCH-STD model is in red, the ORCH-GM simulations are in green. The a priori observation errors on NEE and Qle are shown in grey. The Root Mean Square Error (RMSE) gauges the quality of the model-data fit.*

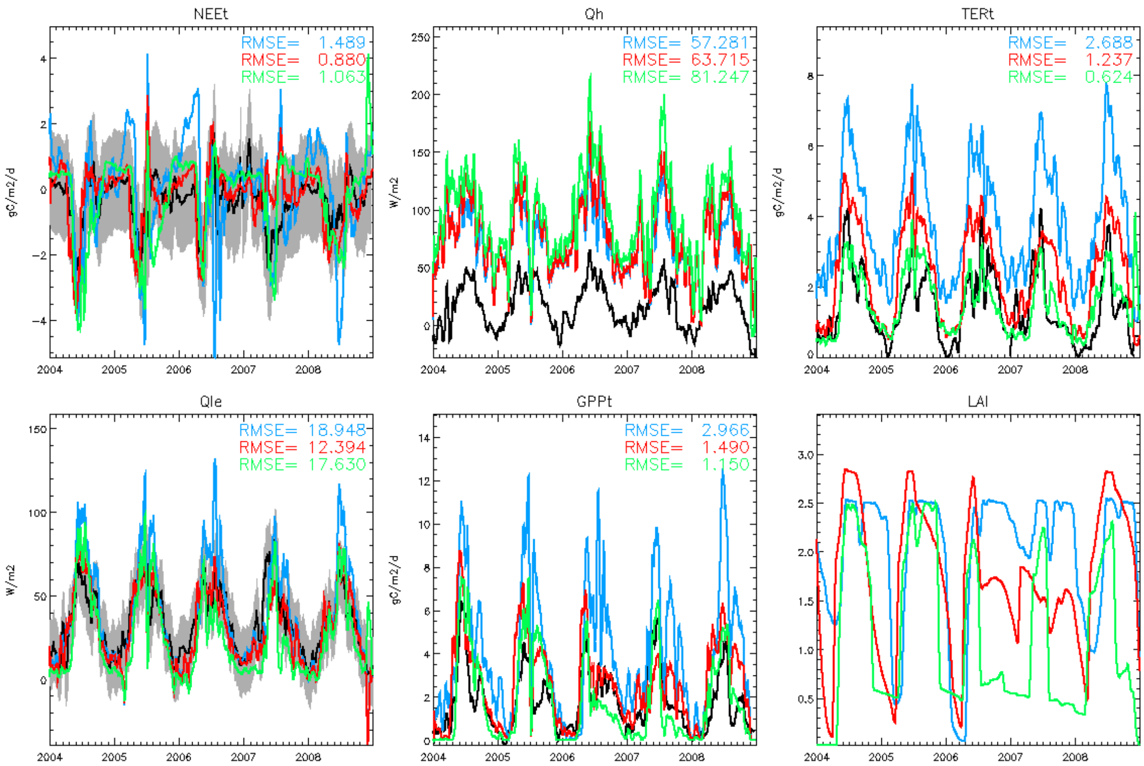


Figure 3.17.: *Same legend as Figure 11 for Alinya.*

Figure 3.18 presents the prior values of the parameters compared to the optimized ones, as well as the associated uncertainty, following the assimilation of daily NEE and Qle fluxes at Alinya and Stubai. In general, the assimilation usually leads to a reduction of the error on the parameters. For a given parameter, the amount of change in the error informs on the constraint brought by the assimilated data to the parameter optimization. The comparison of the estimated values at the two sites shows contrasted results, which was expected considering the difference in the management practices. The variation of the optimized phenological parameters that control the start of senescence differs from the assimilation conducted on the remote sensing products. This is a direct consequence of the fact that the ecosystems are managed and therefore the end of the growing season is not driven only by meteorological forcing. It is interesting to note that the major parameters that control carbon assimilation on the annual scale and that drives the magnitude of NEE seasonal cycle vary interestingly in similar ways. In both cases, the posterior values of *Vcmax_opt* are lower than the priors. This is a bit surprising for the Intensive Stubai site where higher values were expected: The value inferred for the ORCH-GM simulations is 74 µmol.m^{-2}.s^{-1} for Stubai; the optimized value of 62 µmol.m^{-2}.s^{-1} is then closer to the value of alpine (60 µmol.m^{-2}.s^{-1}) or extensive (66 µmol.m^{-2}.s^{-1}) grasslands. The value retrieved for Alinya (54.3 µmol.m^{-2}.s^{-1}) is below the range of variation of the measurements performed in the Alinya area (59-65 µmol.m^{-2}.s^{-1}), which are nevertheless lower than the prior value of the ORCHIDEE parameter.
Nevertheless, the parameters are correlated along the optimization process and the value of one parameter makes sense in regards to the values of the other optimized parameters, as outlined in figure 3.19 that show the correlation strength between the parameters. We can see for instance strong correlations between the parameters acting on photosynthesis and soil water availability (*Vcmax_opt*, *Fstressh*, *Gsslope*, *Tphoto_opt_c*, *Humcste*). The optimized values of *SLA* for Alinya, 0.026 m^2.g^{-1}, are in the range of variation of the site measurements (0.022-0.032) while it is lower for Stubai (estimated value of 0.02 m^2.g^{-1} where the mean values for alpine, extensive and intensive, grasslands are respectively, 0.03, 0.035 and 0.039).

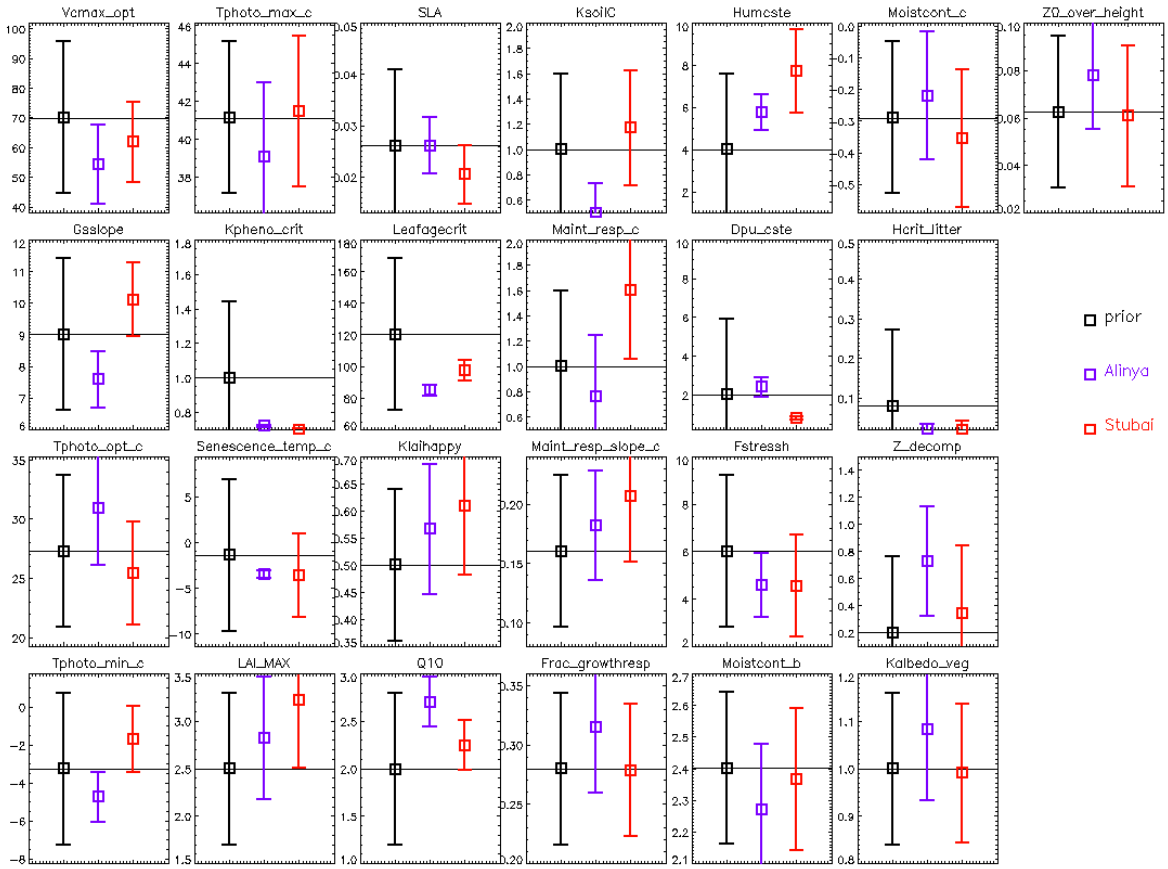


Figure 3.18: *Parameter values (squares) and errors (vertical bars) prior and posterior to the assimilations of the daily means of the NEE and Qle fluxes. The prior values are in represented in black; the estimates derived for Alinya are in blue; the estimates derived for Stubai are in red. Boxes height embodies the range within parameters are allowed to vary during the optimization process. Horizontal lines are the a priori values of the parameters.*

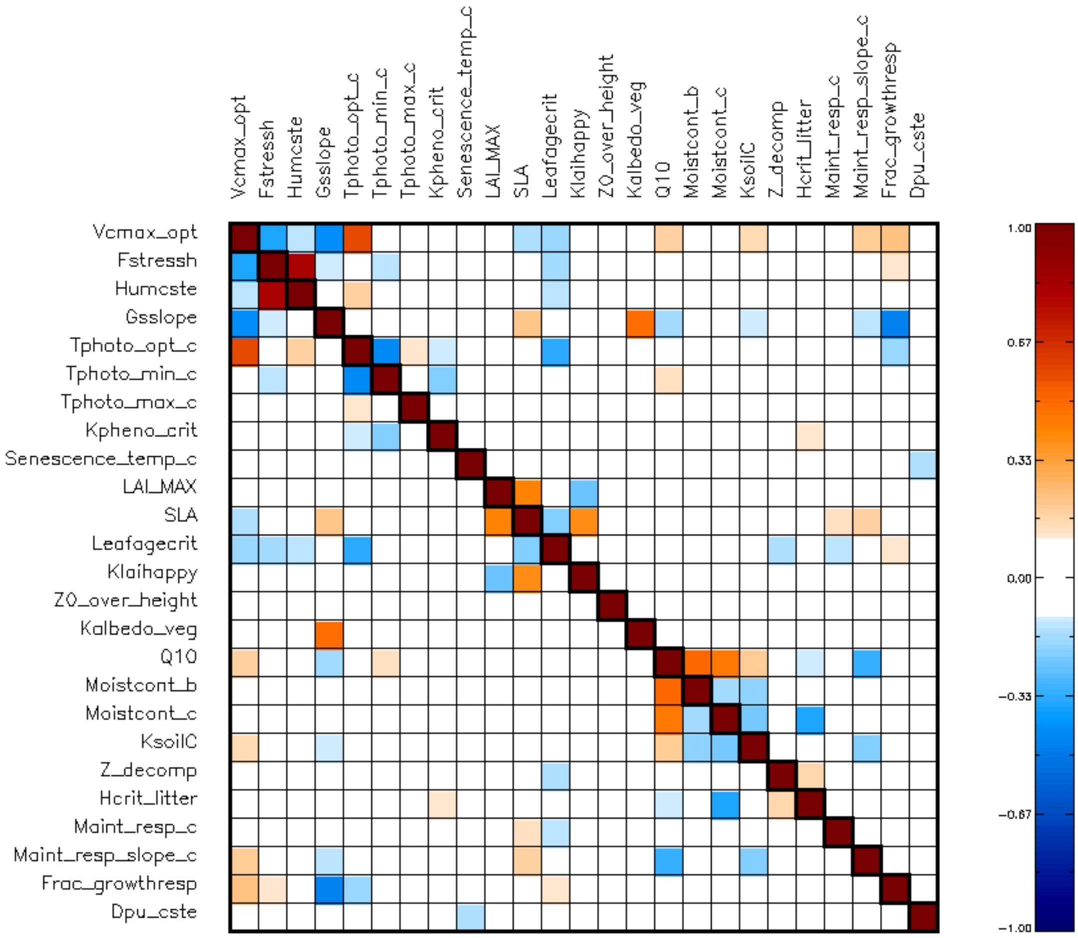
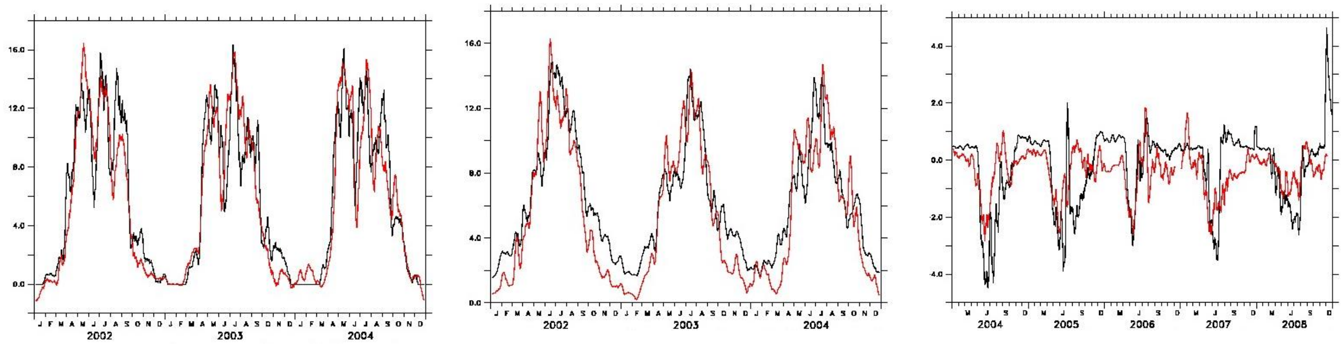


Figure 3.19: *Correlation matrix between the optimized parameters at the Stubai site.*

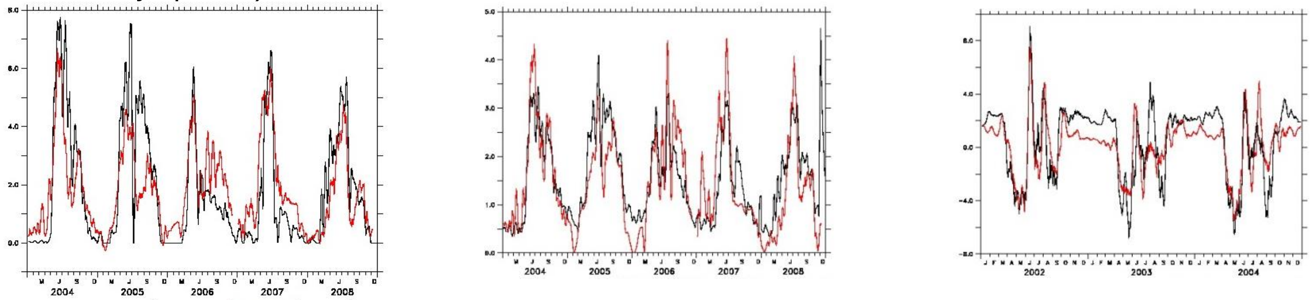
Calibration evaluation and improvement of ORCHIDEE

Figures 3.20 and 3.21 present the simulated and observed fluxes (GPP,Reco and NEE) for both Stubai and Alinya sites taking into account for the management and after calibration for the two sites. The two sites offer the advantage of representing two contrasting management and altitude. For Alinya it is a grazed high altitude (low productive) site, whereas for Stubai is a productive low altitude grassland, cut three times a year. The agreement between model and observation is good. In the midterm report we presented the first simulations and discussed the large discrepancy between simulated and observed total ecosystem respiration. We investigated the reason of this discrepancy and we found that it was mainly related to the way management was taken into account. First we considered that the same management was applied for at least a century with an export of herbage that conducted to a decrease of total soil carbon. Second we investigate more in detail the management of the site and find that site was fertilized with manure and slurry, information that was not in the initial management file for this site. So we have redone the simulations taking into account for these new factors into account. Hence the large bias on ecosystem respiration was removed. This result is very interesting as it demonstrate to important role of management on the net ecosystem flux. In particular it is interesting to see that for Stubai, the carbon added by manure application almost compensate the loss of carbon from herbage export that conduct the site to almost neutral carbon balance.



a/ Gross primary production b/ Ecosystem respiration c/ Net ecosystem exchange

Figure 3.20: Simulated (black: standard ORCHIDEE green: improved ORCHIDEE-Pasim) and observed (red) fluxes at the Alinya site (fluxes are smoothed over a 10 days period)



a/ Gross primary production b/ Ecosystem respiration c/ Net ecosystem exchange

Figure 3.21: Simulated (black: standard ORCHIDEE green: improved ORCHIDEE-Pasim) and observed (red) fluxes at the Stubai site (fluxes are smoothed over a 10 days period)

Functional traits dynamics

CWM of traits were introduced in ORCHIDEE both to compare to standard and optimized value and also to conduct an uncertainty analysis of simulated fluxes and stock related to uncertainty of traits. Two traits was considered in this study. The specific leaf area (SLA) and the maximum rubisco rates Vcmax/Vjmax. In fact Vcmax is in general not directly measured. What is more often measured if the leaf nitrogen concentration. But it has been shown is a large number of studies and in particular in Kattge et al . that there is a linear relationship between leaf nitrogen concentration per area (LNA) and Vcmax. The Kattge et al. 2009 relationship defined for most of the plant functional types (PFT) were used in this study to derive the Vcmax from LNA. For Vercors and Stubai, sufficient data was available to define a mean but also a minimum and maximum trait values for each vegetation classes. Hence four simulations were done: One with standard ORCHIDEE, one with the mean traits value, and two simulations with minimum and maximum. For Alinya there is not sufficient relevés to define a standard deviation. However, for some classes CWM was defined for two subclasses And then 3 simulations was provided: standard and minimum and minimum of traits considering the minimum and maximum traits values given for subclasses. Simulations were done for current climate using the period (1990-2010). Figure 3.22 shows the interval of variation of Vcmax and SLA for the 3 sites and for each vegetation class. The low variation of traits values for Alinya reflect the fact that less releves are available and then less species are used to calculate the community trait mean. If the means values are relatively similar, the estimated traits for each of the site are relatively different both in term of mean values than in term of variability. It should be noted that deciduous forests for Stubai and intensive grasslands for Vercors are not present on the site.

Figure 3.23 shows the corresponding related uncertainties for mean (both the 20 years and the entire region) simulated net primary productivity for the three sites and each vegetation class. Dots indicate the simulation with standard ORCHIDEE. Vercors that only cover high altitude, show the lowest overall productivity. Similarly the productivity is relatively constant over vegetation classes. For instance the alpine grassland does show a high productivity despite is higher Vcmax . For Stubai, the variability of productivity among vegetation class is higher; in particular a clear gradient between the three kinds of grassland is visible. This reflects shifts in plant traits that well correlate with the elevation gradient. Strangely, Alinya for which we have the lowest traits variation show the highest variation between vegetation classes (but not in the range of variation within a class). This reflects the fact that for Alinya the different vegetation classes also experienced the highest difference in climate condition. For instance alpine grassland are located in low precipitation area that conduct to very low productivity. For most of the case the simulation of ORCHIDEE with standard trait value is within the range of variation of productivity related to traits. It should be remembered here that in standard ORCHIDEE, there is only one grassland type and then the same traits value for the 3 grassland types. There is a notable exception for Coniferous forest where standard Vcmax is very low compare to estimated one that lead to a large underestimation of forest productivity.

For Alinya, Alpine grassland show a lower productivity with adapted traits which is coherent with results obtained from optimization on eddy-fluxes. On the opposite for Stubai if estimated fluxes for intensive grassland is in the range of retrieved traits value, but the optimized Vcmax for eddy-fluxes give a Vcmax higher than retrieved value. This could be explained but the fact that the site is well fertilized and then as probably a higher Vcmax that what can be expected for is species composition. Finally is we compare the range of simulated productivity in comparison to range of traits within a class, the variation of productivity is less than corresponding variation of trait. Overall we observed a variation of 40% in variation of trait that lead only to a variation of 34% in the simulated fluxes.

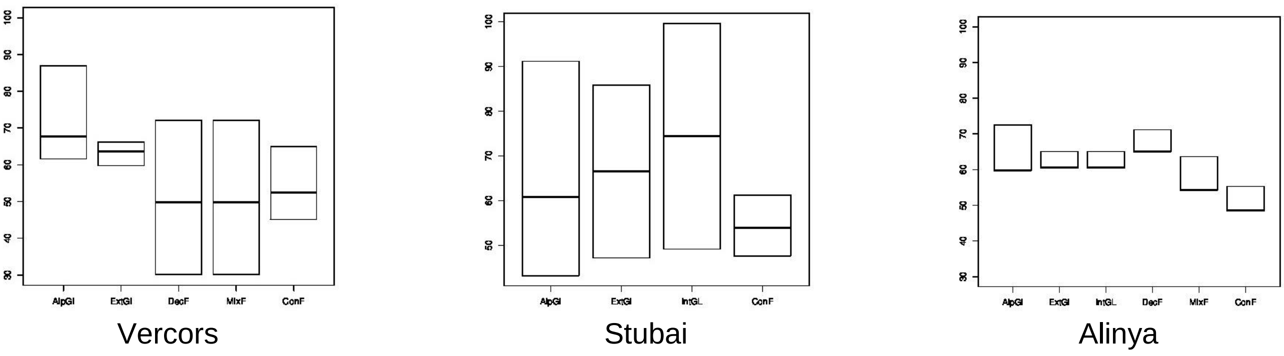


Figure 3.22: range of estimated maximum carboxylation rate (Vcmax,mmol/m2/s) for the different vegetation types and for the three sites.

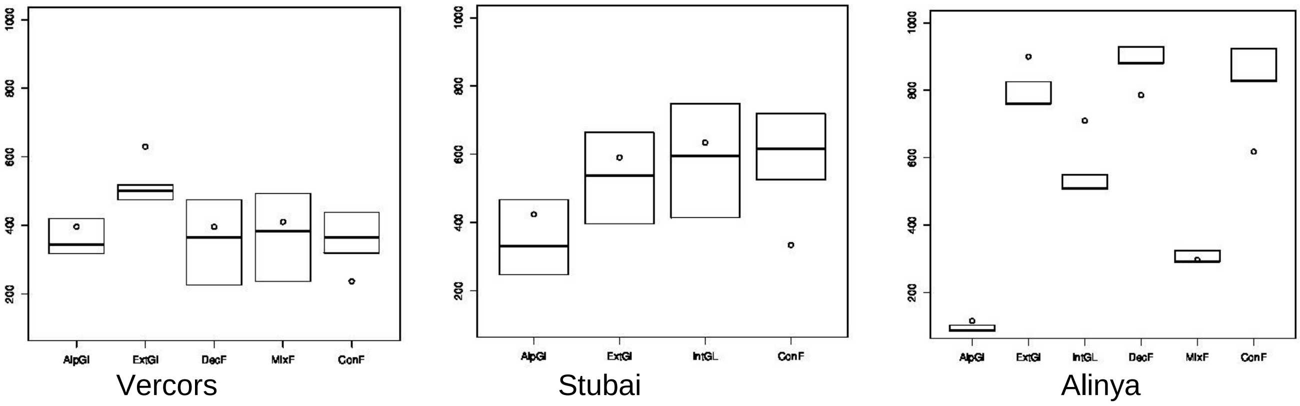


Figure 3.23.1: Range of mean simulated annual net primary productivity (gC/m2/year) for each of vegetation classes. The dots represent the value simulated with the standard ORCHIDEE values of Vcmax/SLA

We also studied the spatial variability of the uncertainties (i.e difference in productivity between high and low traits value) that shows clear spatial patterns. Then we studied the response of the uncertainty to climate parameter. Even if data spread is relatively large, there is an increase of sensitivity to traits with decreasing temperature. This is more evident for the grassland PFT’s. We not investigate the reason, in the model for such relationship but we can guess that is partly related the fact that, because of the bell shape response of photosynthesis to temperature, the change of maximum photosynthetic rate is more sensitive in low temperature.

We detected a lack of information on traits for Mediterranean species. Those species are often missing in the trait databases. This fact is probably affecting the uncertainty in the site of Alinya. A field sampling of different species revealed the extent of the differences in Mean Leaf Dry Matter Content (LDMC, Fig. 23 bis) and Leaf Nitrogen Content (LNC, Fig. 23ter).

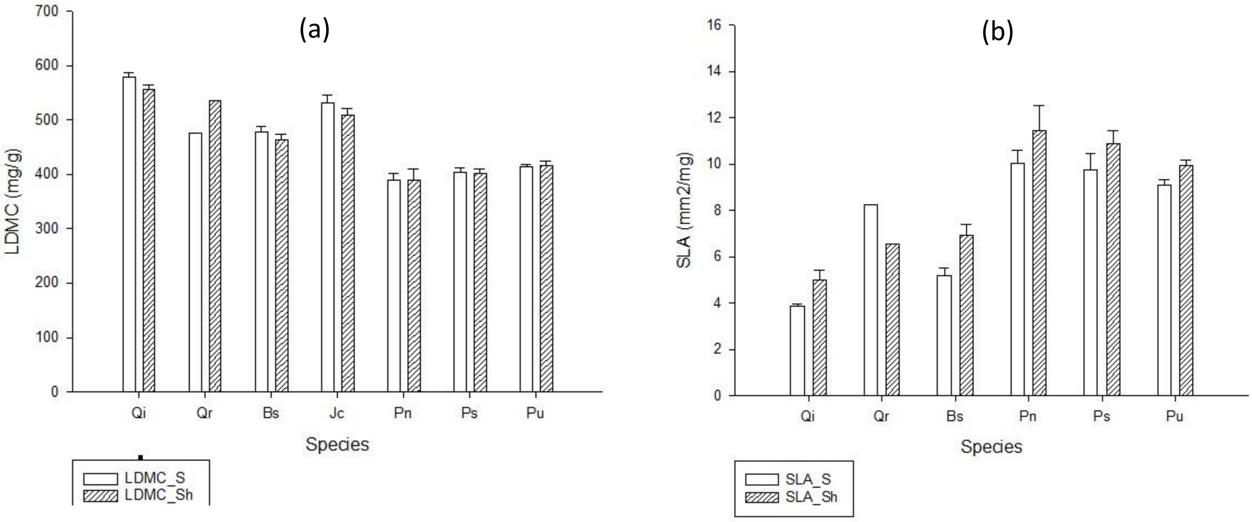


Fig. 3.23.2 (a) Mean Leaf Dry Matter Content (LDMC) values in Alinya, according to species where LDMC_S = LDMC in sunlit leaves, LDMC_Sh = LDMC in shaded leaves. (b) Mean Specific Leaf Area SLA values according to species where SLA_S = SLA in sunlit leaves, SLA_Sh = SLA in shaded leaves. *Qi = Quercus ilex, Qr = Quercus robur, Bs = Buxus sempervirens, Jc = Juniperus communis, Pn = Pinus nigra, Ps = Pinus sylvestris, Pu = Pinus uncinata*.

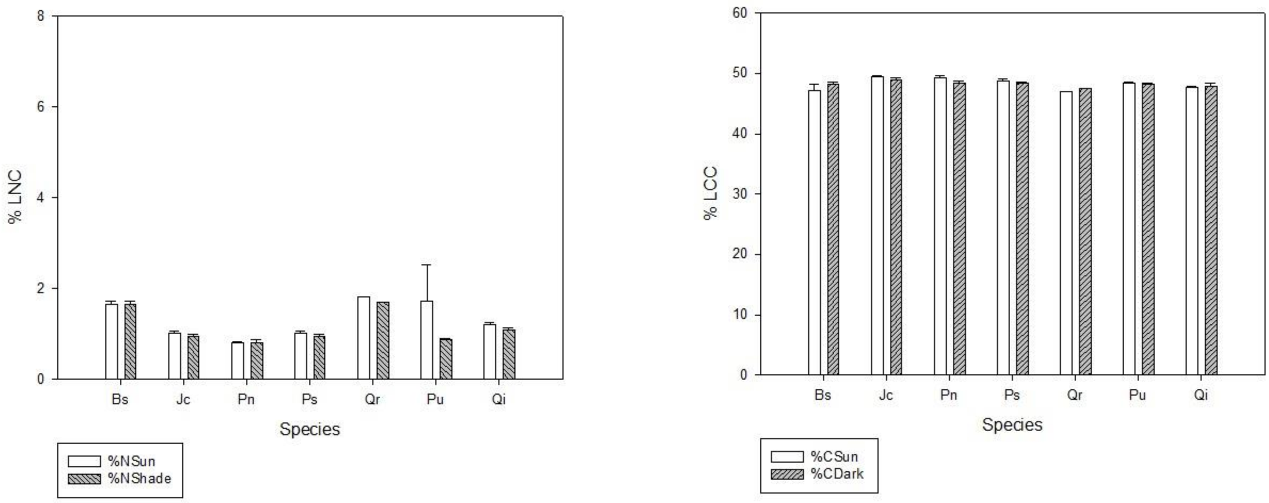
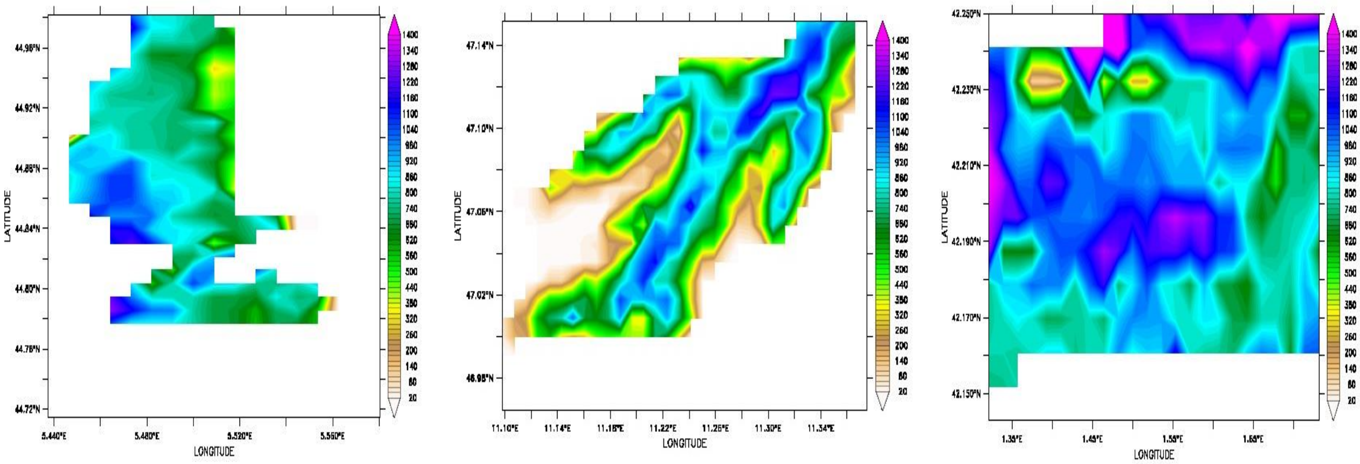


Fig. 3.23.3. (c) Leaf Nitrogen Content (LNC) values according to species in Alinya, where %NSun = % of N in sunlit leaves, %NShade = % of N in shaded leaves. (d) Leaf Carbon Content LCC values according to species where %CSun = % of C in sunlit leaves, %CShade = % of C in shaded leaves. *Qi = Quercus ilex, Qr = Quercus robur, Bs = Buxus sempervirens, Jc = Juniperus communis, Pn = Pinus nigra, Ps = Pinus sylvestris, Pu = Pinus uncinata*.

Historical and future climate and land cover attribution of carbon stock and fluxes variation and trend

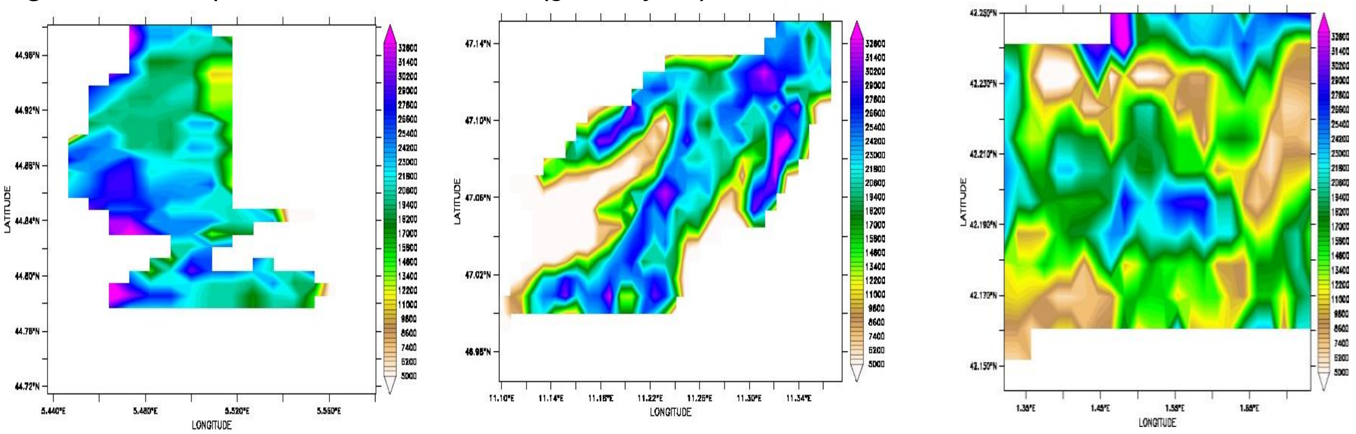
A set of simulations was done both for the historical period (1950-2010) and for the future (2010-2100) to evaluate the change of carbon stock and fluxes for the three sites and to attribute the role of each drivers (i.e climate, co2, land use) in the simulated fluxes. For this purpose several simulations was done keeping one or several parameters fixed whereas others parameters was variable. To take into account for the interannual variability of climate, for simulation with fixed climate we in fact used the period 1950-1960 in loop.
Figure 3.24 show the mean net primary productivity of the historical period simulated for the 3 sites and for the simulation including all factors. We can obviously notice that altitude and then temperature is the main driver of spatial variability of the productivity. Figure 3.25 show the simulated mean total soil carbon also for the three sites. The simulated values (with an average of 21 kgC/m2/year) is higher than commonly observed that is more around 15kgC/m2/year but the comparison is difficult because we consider here the total soil carbon whereas observation is only based on a fraction of soil. Moreover simulation begin from an equilibrium of the soil carbon with the climate of the 50' which is probably not realistic and overestimate the initial soil carbon, but can be the only possible assumption as we don't have the century scale climate and land use data !

It is also interesting to notice that altitudinal gradient of soil carbon is less pronounced that for NPP because lower decomposition rate at low temperature partly compensate for decrease of productivity.



Vercors Stubai Alinya

Figure 3.24: Maps of Mean annual NPP (gC/m2/year) simulated for the 3 sites.



Vercors Stubai Alinya

Figure 3.25: Maps of mean total soil carbon (gC/m2) simulated for the 3 sites.

Figure 3.26 and 3.27 show the temporal evolution of productivity, net co2 flux and total ecosystem respiration for the different fluxes for Stubai and Vercors respectively. We can see than productivity and net carbon flux that was stable before suddenly increase after the 1980’s. This productivity trend is projected to continue to increase in the future until first half of the 21th century but then tend to stabilize even begin to decrease at the end of the century for Vercors. This is even more pronounced for net co2 flux where the rate of soil carbon storage begins to decrease after the second half of the 21th century especially for Vercors. Hence whereas productivity reach a plateau, the increasing temperature continue to stimulate the increase of ecosystem respiration. The difference between Stubai and Vercors could be explain by the fact that for Vercors, climate scenario indicate a small but regular decrease of precipitation that increase the summer drought whereas for Stubai, in opposition, there is a slight increase of precipitation.

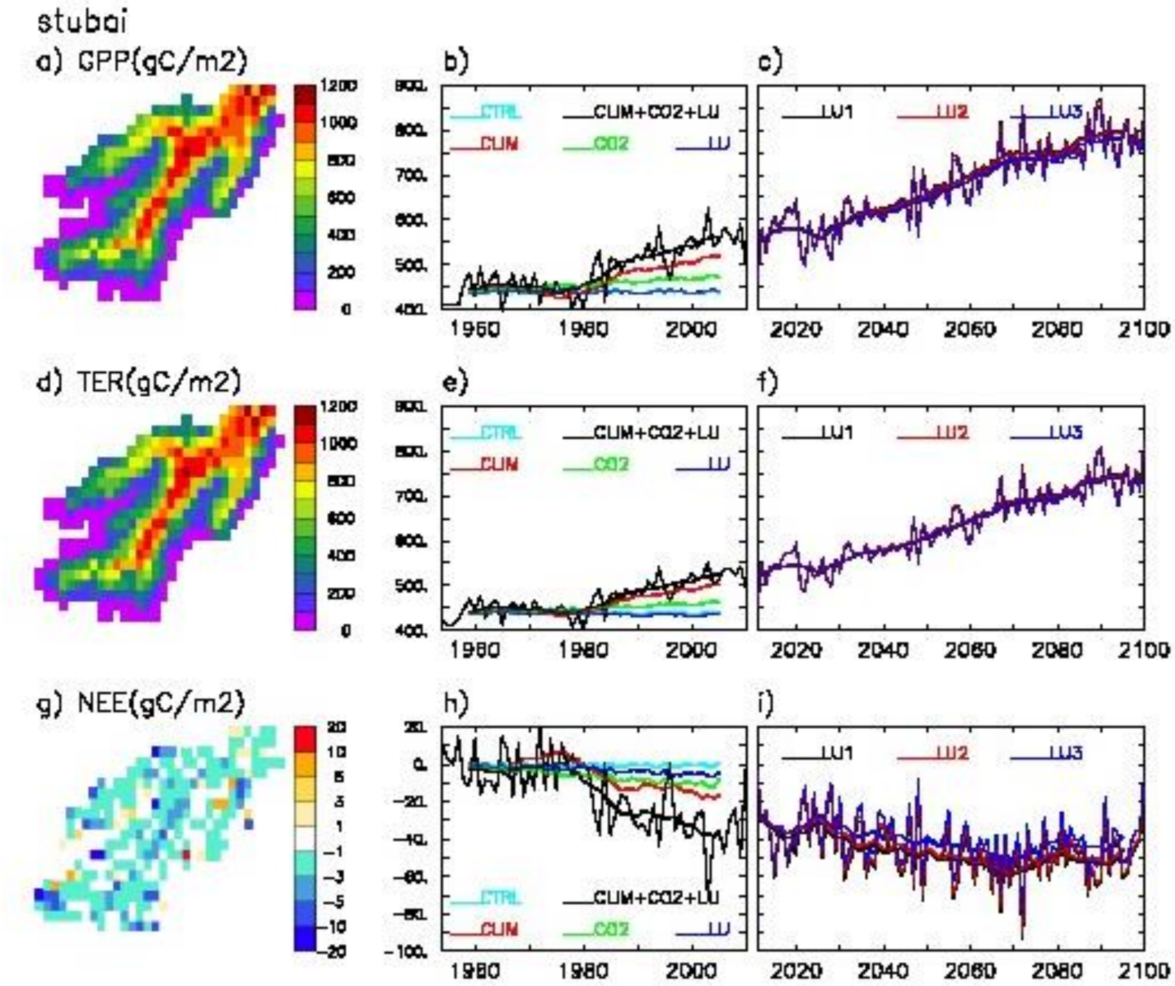


Figure 3.26: Temporal evolution of GPP, Total ecosystem respiration (TER) and net CO2 flux (NEE) for historical and future period and with the different sensitivity analysis. For future, only the simulations with the different land use scenarios are reported.

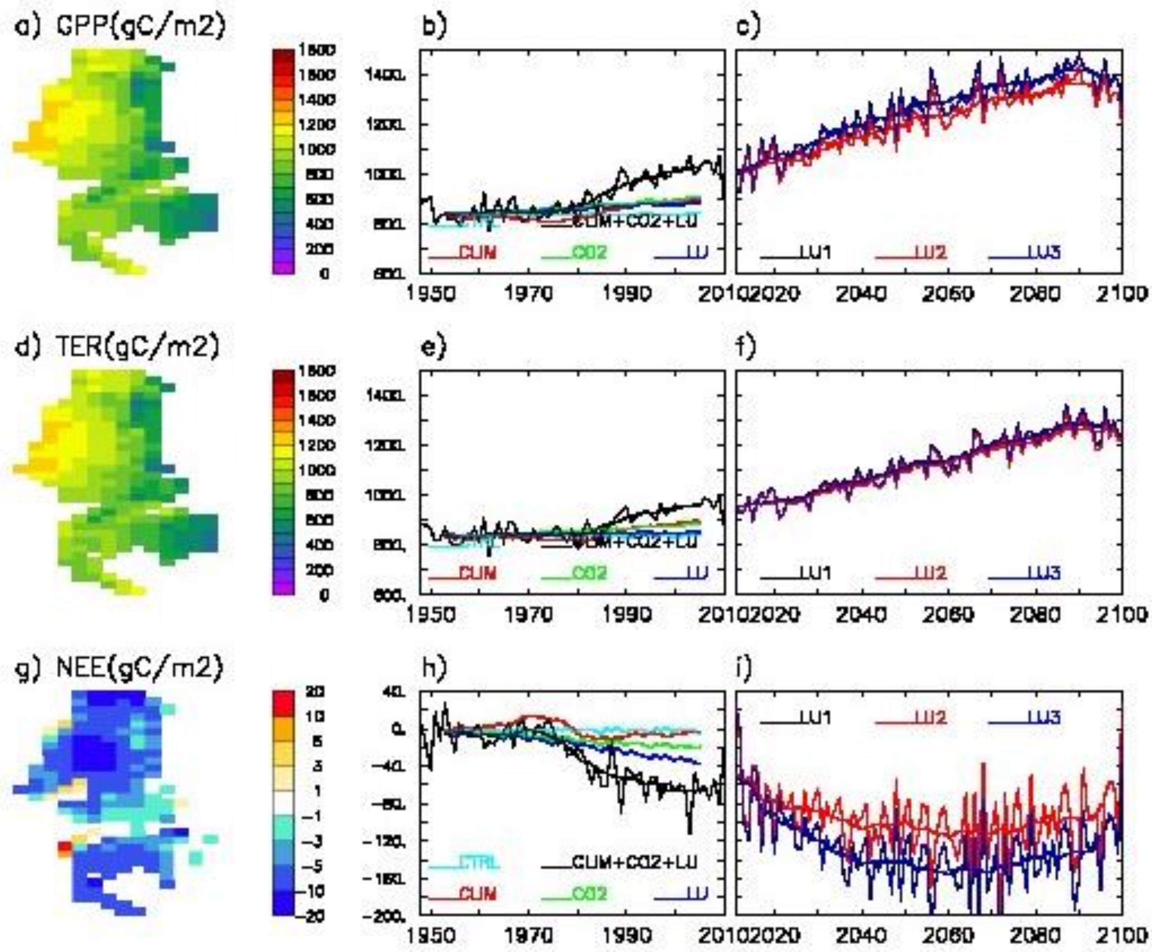


Figure 3.27 : same as figure but for Vercors

Figure 3.28 to figure 3.33 summarize the impact of each driver on the trend observed during 1950-2010 separating the response on forest and grassland. For Alinya, as we not yet have the land cover change maps, only the effect of climate and CO2 are represented. For Stubai and Vercors, If we exclude the land use effect, the main driver for his positive trend is the temperature increase followed the CO2 fertilization effect. This result is interesting as it differs from previous studies done with ORCHIDEE for non-mountain regions. Indeed for most of the regions, CO2 increase is the main driver of the observed trend on the recent period. For mountainous ecosystem where temperature is the most limiting factor, the increasing temperature has a positive effect on the length of the growing period and a positive effect on photosynthesis during summer. By contrast, the reduced precipitation in Alinya largely counter balanced these positive effects of temperature resulting in a large negative climate trend on the productivity. As there is also a large decrease of respiration the effect on net co2 flux is reduced but there is however a relatively large source of carbon. The CO2 effect that here play a double role by the direct fertilization effect and by indirect effect on improving the water use efficiency by stomatal closure has a large impact on productivity. Hence when combining the different effects, the productivity slightly increase despite the negative effect of the climate.

For land cover change, because it is mainly driven by forest dynamics, decrease the total productivity of the grassland system in favor of forest. The effect is more pronounced for Vercors where the forest increase is more important. Because forest productivity is a higher than that of grassland, the overall impact is a small increase of total productivity. Figure 3.31 to 3.33 show the equivalent of figure for the projected scenarios. The bar on impact of land use indicates the uncertainty related to the different land use scenarios. The relative impact of each factor is not very different from the historical period except that amplitude if higher.

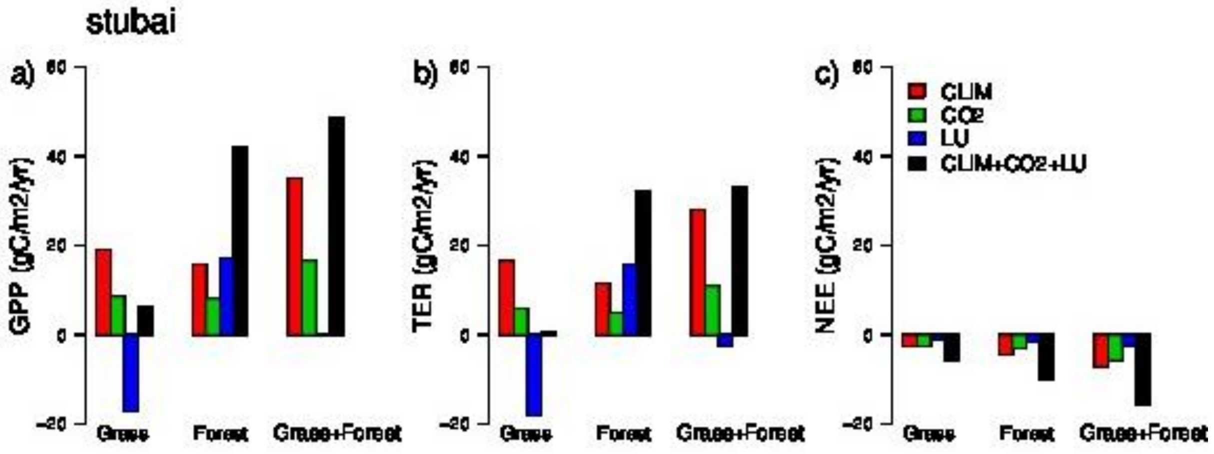


Figure 3.28: attribution of impact of each driver in carbon fluxes trends (productivity, total ecosystem respiration and net carbon flux) for Stubai

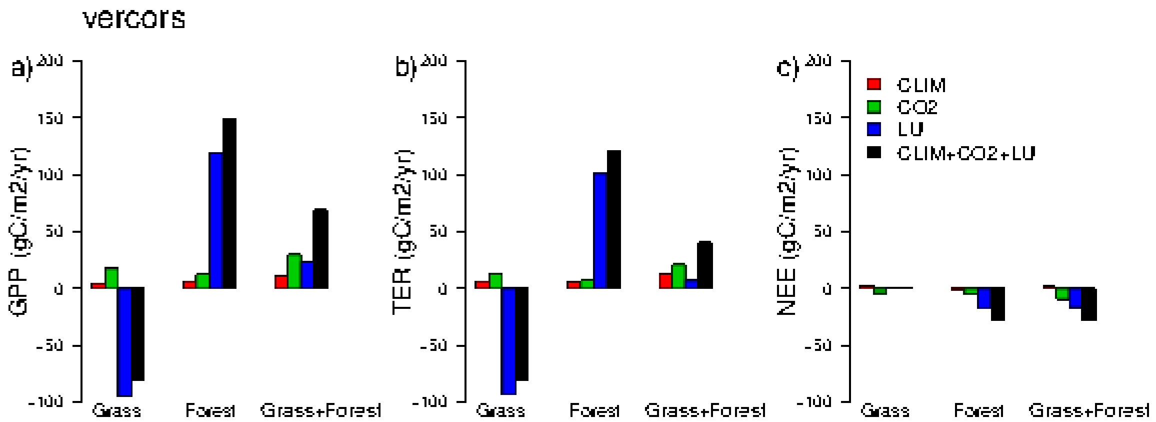


Figure 3.29: attribution of impact of each driver in carbon fluxes trends (productivity, total ecosystem respiration and net carbon flux) for Vercors

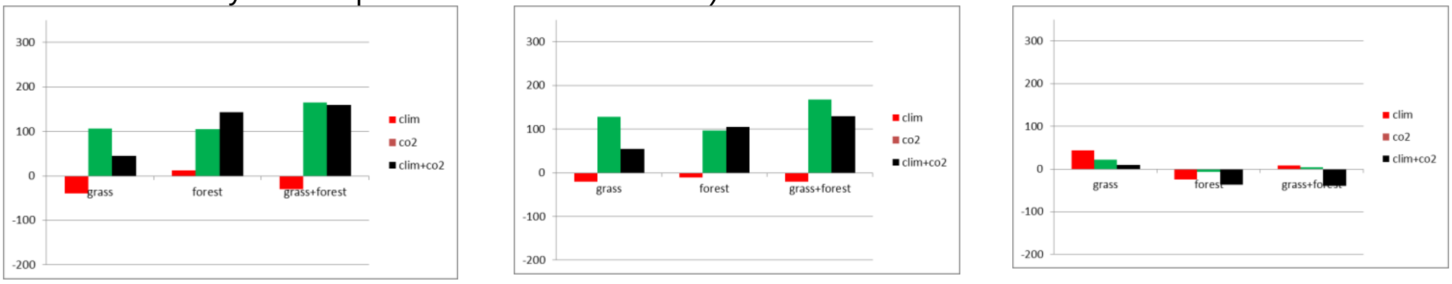


Figure 3.30: attribution of impact of each driver in carbon fluxes trends (productivity, total ecosystem respiration and net carbon flux) for Alinya

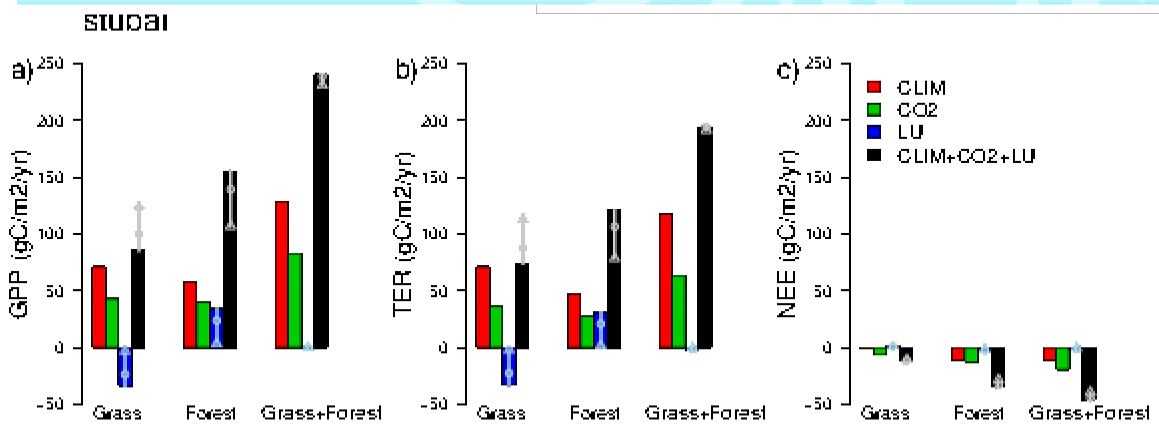


Figure 3.31: attribution of projected impact of each driver in carbon fluxes trends (productivity, total ecosystem respiration and net carbon flux) for Stubai

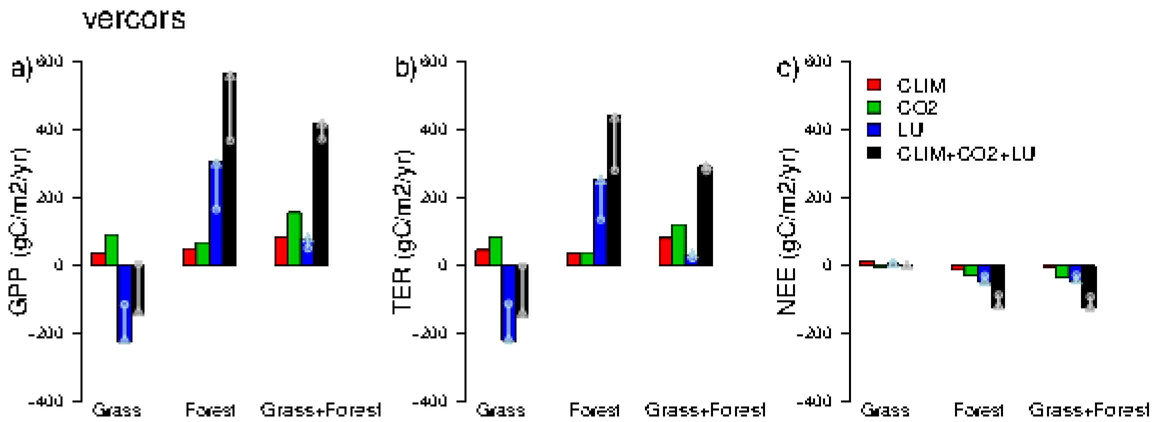


Figure 3.32: attribution of projected impact of each driver in carbon fluxes trends (productivity, total ecosystem respiration and net carbon flux) for Vercors

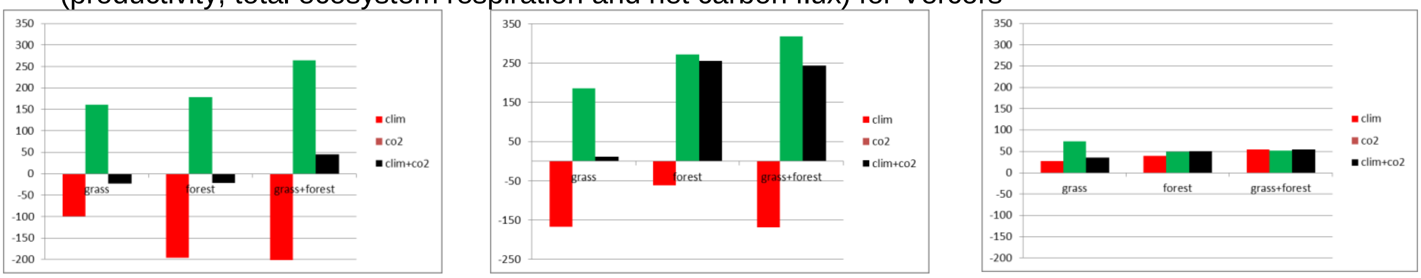


Figure 3.33: attribution of projected impact of each driver in carbon fluxes trends (productivity, total ecosystem respiration and net carbon flux) for Alinya

Response of animal production to climate and land cover change

As described in the work progress of the new WP330, we used the newly automatic management module developed in ORCHIDEE to test the possible adaptation of sustainable animal stocking rate for the three region of interest. In the previous simulations, we run ORCHIDEE in standard mode considering only the ecosystem productivity without interaction with animals. In this study we used ORCHIDEE-GM to simulate the animal stocking rate and productivity and its adaptation to climate change. Like for previous study we considered both the historical and future period and the different land use scenarios conducting a series of simulations with the different driving factors. As we not yet finished all the simulations, in particular Alinya with land use and Vercors without land use we compared Stubai and Alinya with a simulation where land use is held to present one and Stubai and Vercors taking into account for the land use.

Figure 3.34 shows the evolution of the simulated optimum total animal that can be feed from grazing and forage for Stubai and Alinya. For Stubai, the enhanced grassland productivity related to climate and CO2 fertilization allow increasing the total number of animal during all the 21th century. For Alinya, because of the very limited productivity does not increase, even with a small decrease by the end of the century, on the opposite, the possibility to increase for the future, there is almost no increase of animal density for the future.

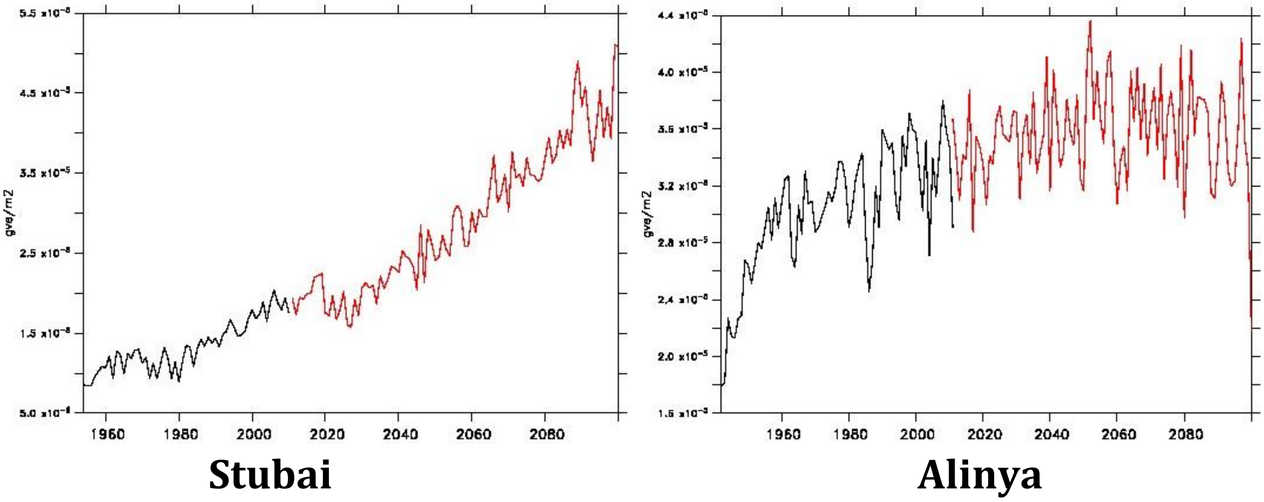


Figure 3.34: Evolution of optimum number of animals between 1960 to 2100 (without land cover change)

On figure 3.35 we plotted the evolution of the animal density and total number of animals for Stubai and Vercors taking into account for the three land use scenarios. For Stubai, we plotted the results from the different factorial experiments. Even if the land use change is moderate, its impact on animal production is important and can counterbalance the climate and CO2 effect. Indeed if the total grassland area does not change a lot, there is a change between intensive and extensive. Hence between 2000 and 2020 there is a decrease of intensive (cut grassland). As intensive grassland is more productive than grazed one there is a large decrease of animal density. For Vercors the result is very different even is the change of grassland area is higher than Stubai. For Vercors one of the limiting factors is the possibility to feed the animals from Crau forage from which area is assumed to be constant. Then for Vercors the animal production is conditioned by production both from Vercors and Crau that experiment different climate change condition. Increasing aridity in Crau does not allow increasing the forage production. For this reason the scenario that show the larger increase of grassland surface can only partly benefit from this surface increase and then animal density decrease allow a small change in total animal because the But this is compensated by an increasing period where animal can grazed in Vercors. Hence by extending the period of grazing, it is possible to increase the number of animals. Another interesting feature is to look at the interannual variability of productivity. The algorithm used to calculate the dynamic of animal production evaluate each year a surplus or deficit of forage that allow the estimate the adaptation of new animal density. By construction, this variable as a null mean (i.e over a period of 20 years, the surplus compensate the deficit). But it is interesting to study the interannual variability of this variable. Indeed it gives some indication about the possible fluctuation of feed needs. Hence, if we simulate and increase of potential animal density, this increase is associated with an increase of variance of the feed surplus/deficit (that follows in fact the increasing variance of the climate). Then the advantage of potential increase of animal production is associated to an increase of system vulnerability. This factor is not taken into account in the algorithm but should in reality conduct the farmers the stay on suboptimal conditions.

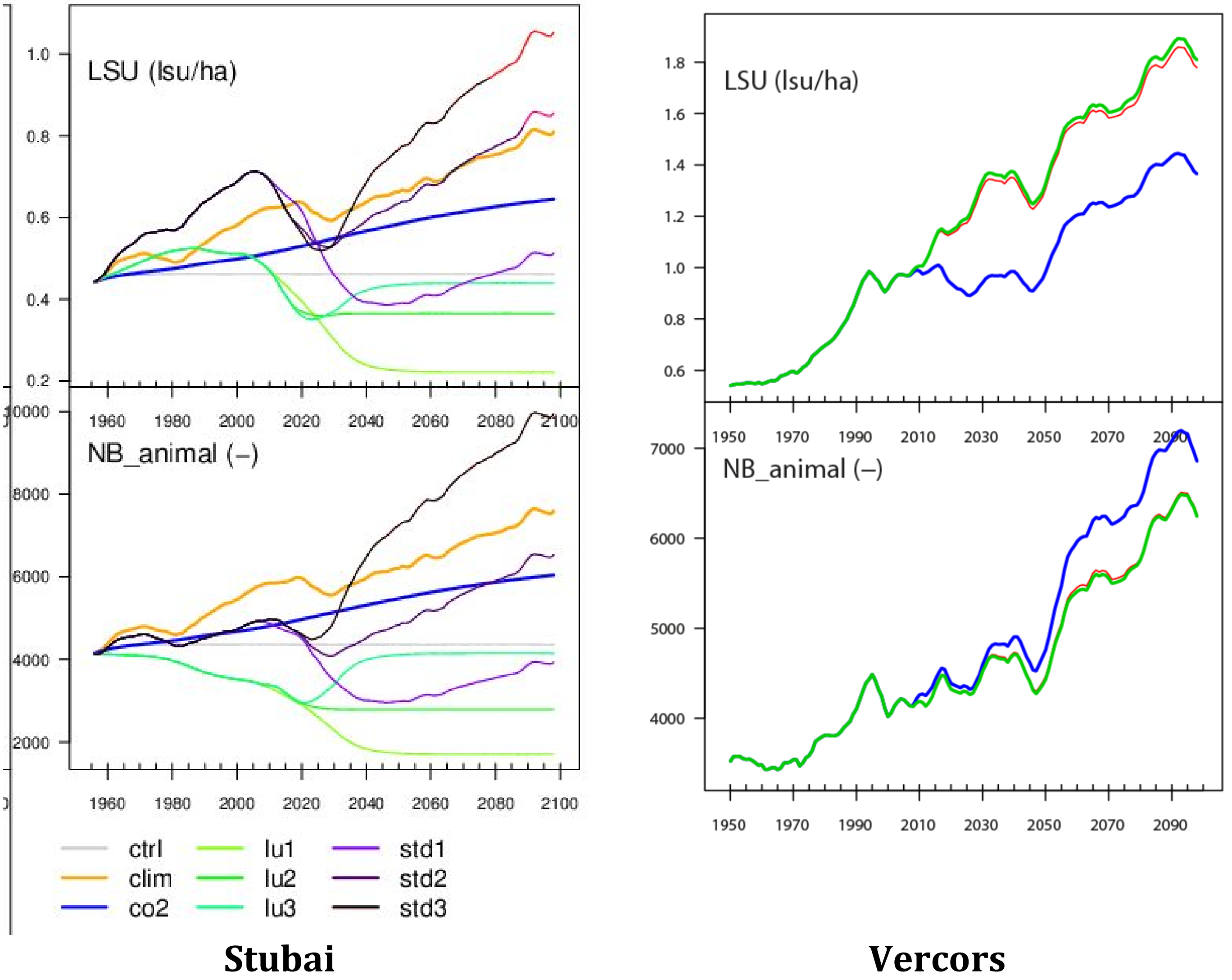


Figure 3.35: Evolution of livestock unit LSU (or animal density) and total number of animal for the three land use scenarios for Stubai and Vercors. For Stubai each curve represent a factorial experiment. (ctrl:no change), (clim:climate only),(co2:co2 only), (lu1,lu2,lu3: land use 1,2,3 only),(std1,std2,std3: all factors land use 1,2,3). For Vercors only std1, std2,std3 are represented

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3. Synthesis and main conclusions

The CAMELEON project was challenging on several aspects. First of all it was a very pluri-disciplinary research project putting together research groups from climate and global biogeochemical sciences and remote sensing working at large scale and on the other hand groups from ecology and social sciences working at more local scale. So for the ecological group it was a challenge to compile very different data at a scale of a region of around 300 km2. On the opposite it was a challenge to apply a global vegetation model like ORCHIDEE at a 1km2 grid cell with new kind of PFT (i.e several kind of grasslands). A first important result is the availability of a unique database for three regions of interest. Hence a detailed set of land cover changes maps from the 50's and projection for the next 30 years was constructed. We could then find a common trend of grassland abandonment that should continue in the future with local conservative scenarios but that can on the opposite invert the trend in case of socio-economics intensification. Behind the CAMELEON project, such detailed land use map will be of large interest for a wide scientific community but also for the local stakeholders.

The second dataset concern the compilation of plant functional traits at the level of the main vegetation classes we defined for the project. This was a huge task as the data is sparse and this was only possible thanks the TRY trait database initiative necessary to fill the gap in missing species. Even if there is a still large uncertainty on these traits variability it was possible to define aggregated traits at the community level. Even if we was not able to derive new relationships between traits and climate that we could include in ORCHIDEE, we was able to access the uncertainty of simulated carbon fluxes related to functional traits at community level. For our knowledge, it is one of the first studies that attempt to do such uncertainty analysis. Another challenge of the project was to try to use remote sensing data on mountain area which is a particularly complex case because of the topography. Among the different datasets, only SPOT-VGT was suitable for such kind of study. It was then possible to characterize the phenology of the vegetation and its interannual variability showing complex patterns not simply related to altitude and temperature. As mentioned before, another big challenge was to use ORCHIDEE, a global vegetation model, at high resolution on complex mountainous systems. The different kind of data from traits, eddy fluxes or remote sensing compiled at regional level was however a unique opportunity to evaluate the model. The comparison with traits data shown that, except for conifer forest where the model productivity was largely underestimated, without optimization the model simulation of carbon fluxes was most of the time within the range of estimations based of prescribed trait values from observation. The optimization procedure done on the model is also very important as it allows understanding which part of the discrepancies comes from the fact that parameters are not correctly prescribed or comes from lack of processes in the model. In particular it was interesting to see that, even on the interannual scale, discrepancies in annual phenology anomalies between model and observations can be reduced after optimization. Likewise the fact that a global calibration largely improves the model skill for each site indicates a certain level of process genericity. The comparison between model and eddy-fluxes also demonstrate a good agreement between model and observation as far as we have a good description of the management. It also demonstrated the important role of management in the measured fluxes. It was interesting to notice that because of organic fertilizer applied to Stubai, the site is almost carbon neutral whereas we could expect a large sink because of biomass removing.

The response to climate change for mountainous region appears to be more favorable than other regions because, increasing temperature has a large positive impact on productivity. The three sites however shown a contrasted response depending on the change in precipitation in the climate scenario used. Stubai show the largest increase of productivity because both temperature and precipitation increase. On the other side, for Alinya, the precipitations increase, increasing summer drought. The effect of drought is moderated by the CO_2 effect that avoid a too large effect on productivity that only show a decrease by the end of the century. Vercors is an intermediate case where precipitation is slightly decreasing allowing an overall increase of productivity but less important than for Stubai.

The recent development of the new grassland management module in ORCHIDEE allows us to go a step further and try to simulate the possible adaptation of the animal production systems to climate and projected land use scenarios. Here again the three sites show contrasting systems as Stubai and Alinya are mainly based on local systems whereas Vercors is based on a transhumant system with the Crau plain. Obviously the capacity of animal production largely follows the change in grassland productivity. Hence for Stubai, there is an important potential for increasing animal production, whereas for Alinya on the opposite, production could decrease by end of the century. For Vercors the situation if more complex since as for Alinya, we simulate a small of even slightly decrease of productivity in Crau, It is partly compensated by the increasing potential of grazing in Vercors. Hence there is an overall capacity of slightly increase the animal production, but less that could expected from the change in grassland productivity itself.

All these results are very preliminary and should be considered with caution. In particular the relatively optimistic results in term of response to climate change should be moderated by several aspects:

1. As we have shown, if the productivity increasing its variance also increase with very high but also very low productivity years, that is obviously a big problem in term of vulnerability
2. The scenario we used is a relatively moderated scenario in term of climate change. This will be possible in the near future with the new EURO-CORDEX new scenarios, but unfortunately, it was not available during the CAMELEON project
3. The response of vegetation to increasing CO_2 is still controversial. In particular the ORCHIDEE model does not include yet the expected nitrogen limitation for the future. More generally the different FACE experiments have shown that increasing productivity in double CO_2 is around 15% (with large interspecies variability) instead of the 30 to 40% theoretically expected (and simulated by ORCHIDEE). As we have seen, in the factorial experiments, the climates change as only a small positive effect (and largely negative effect for Alinya) on productivity. So we probably overestimate the increase of productivity.

4. Publications/communications

- Including added value for the proposed research area,
- Place, role of the project and project results in the international, national cc agenda and
- links established and synergies to other projects

DIVGRASS is a FRB (Fondation pour la Rechereche sur la Biodiversité) funded project that aims to integrate and share existing knowledge on plant diversity in French Permanent Grasslands (i) to characterize the climatic and land use determinants of community-aggregated traits, and (ii) to improve the representation of the C3 grasslands in Land Surface Models by using spatially distributed vegetation parameters. Therefore, DIVGRASS and CAMELEON share a common objective of incorporating plant functional diversity in biogeochemical models.

Likewise CAMELEON is also related to another French ANR project: GREENLAND who aims to better understanding the relation between local population (including agriculture) and the climate change from medieval to future period. In this project, ORCHIDEE is also involved to simulate the change in grassland and animal production. Obviously as ecosystems are not very different from mountainous one, the GREENLAND project will largely benefit from the results of CAMELEON.There are also links between CAMELEON and several FP7 European projects: CEXTREM who aims to study the impact of extreme event on carbon cycle and ANIMALCHANGE who aims to understand the impact of climate change grassland systems.

Submitted papers:

Carlson, B. Z., C. Randin, I. Boulangeat, S. Lavergne, W. Thuiller, and P. Choler. *in press*. Working toward Integrated Models of Alpine Plant Distribution. Alpine Botany.

Carlson, B. Z., J. Renaud, P.-E. Biron, and P. Choler. *submitted*. Long-Term Modeling of the Forest-Grassland Ecotone in the French Alps: Implications for Pasture Management and Conservation. Ecological Application.

Vicca S., Bahn M., Estiarte M., Alberti G., Ambus P.; Arain M.A.; Beier C., Bentley L., Borken W., Buchmann N., Collins S.; de Dato G., Dukes J. et al. (submitted) Can current moisture responses of soil respiration be extrapolated into a future with altered precipitation regimes? A synthesis of precipitation manipulation experiments. Submitted to Global Change Biology

Papers in preparation:

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Effect of climate, CO2 and land use over three contrasted mountainous regions

Zhao Y Chang J. ., Choler P. Renaud J. Bahn M. Heinl M. Tappeiner U. Bacour C. ., Debouk H., Íñiguez E., Teresa M.-T. Sebastià, M.S Viovy N, *in prep*
Possible adaptation of animal production over three contrasted mountainous regions

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5. Relations and involvement of stakeholders

As explained it the work around WP 4, Stakeholders was involved directly in the project both by defining the future land use scenarios and also by providing several information about management practice for the three regions.

Future land-use in the Stubai Valley was discussed with stakeholders (local farmers) during half-day workshops on 8.11.2011 and 6.12.2011 in Neustift.

A qualitative interpretation of the global storylines of the Intergovernmental Panel on Climate Change (IPCC) was presented. Several scenarios was presented related to local and global socio-economic scenarios and the 5 and 20 years climate scenarios.

Then semi-directed interviews with 6-10 key stakeholders were organized to identify distinct regional trends in the driving forces and projected land-use trends.

Focus group discussions were done with local farmers to assess the importance of sociotechno-economic drivers on management strategies.

For the Vercors site, semi-directed interviews with 15 stakholders (comprising farmers, land managers, and policy makers) have been done in the framework of the PhD project of Manar Hatem (completed in 2011). Based on this material and IPCC scenarios, we have proposed 4 contrasting views of the landscape and socio-economical changes for the Vercors site. These scenarios have been completed with information provided by the European project MOUVE that focused on a nearby area (north of Vercors). The main work was to produce land cover change maps corresponding to 2 scenarios and discuss the outcomes of this work with stakeholders.

After the end of the project, during next autumn, a local meeting for the three region will be organized to present a synthesis of the main results of the CAMELEON project