CONFERENCE PROCEEDINGS

Assessment of full carbon budget of Italy: the CarbIUS project

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Abstract

The Carbon Regional Balance Italy-USA (CarbIUS) is a joint Italian-US program to quantify and compare regional carbon balances, funded, for the Italian side, by the Italian Ministry of Environment in the context of a bilateral agreement to develop scientific collaborations in Global Change Research between Italy and USA signed in 2001.
The two regions selected are Italy and Oregon-California; there are many similarities between these two regions (climate, vegetation, topography, population pressure, etc.) but, on other hand, there are also interesting contrasts in societal aspects like demography, land-use history and emissions.
The main CarbIUS objectives are 1) the identification of spatial and temporal variability of carbon sources and sinks and the relative contribution of the different anthropogenic and biogenic components, 2) the impact of land use changes and human population dynamics on the carbon balance, 3) the quantification of the effects of climate and natural disturbances on the terrestrial carbon stocks and fluxes and 4) the application of new methodologies to investigate carbon metabolism at the plot, ecosystem and regional scale.
In this paper will be presented the methodologies that we are using to assess the contribution of the different components to the full carbon budget, like carbon stocks and fluxes, disturbances (harvesting, wild forest fires and forest pathology), CH_4 and NO_2 fluxes and anthropogenic emissions. All these information will be input in a Data Assimilation System and the results will be validated using sub-regional airborne measurements of carbon fluxes.

1) Introduction

The Carbon Regional Balance Italy-USA (CarbIUS) is a joint Italian-US program to quantify and compare regional carbon balances, funded, for the Italian side, by the Italian Ministry of Environment in the context of a bilateral agreement to develop scientific collaboration in Global Change Research between Italy and USA signed in 2001. The agreement outlines, among others, the relevance of carbon cycle research in the context of the expected changes in the global climate and the global environment.
The two regions selected are Italy and Oregon-California (Figure 1); there are many similarities between these two regions: climate types, structure of the terrestrial vegetation and a convergent evolution of terrestrial ecosystems. Both Italy and California-Oregon are regions with physiographic aspects in common as, for instance, long coastlines, mountain ranges parallel to the coast and the co-existence of different land use types. Other commonalities are related to their well developed industrial economies of similar magnitude, strong urbanization, and significant population pressure.

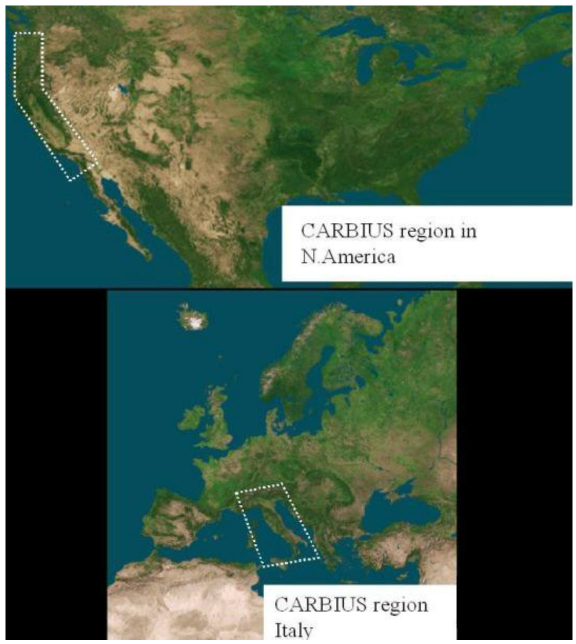

Figure 1: the CarbIUS region in Italy and US (ORCA-NACP project)

On the other hand, there are also interesting contrasts in societal aspects between the two regions; the western coast of the US is experiencing rapid growth of the population and the economy, while Italy is in steady state. And such a contrast offers an extraordinary opportunity to improve our understanding of the carbon balance and the role of human and natural disturbances in perturbing the terrestrial carbon cycle. Moreover, this provides a challenging opportunity to test our current capacity to measure and verify the net carbon balance at the regional scale
The main CarbIUS objectives are

1) the identification of spatial and temporal variability of carbon sources and sinks and the relative contribution of the different anthropogenic and biogenic components;
2) the impact of land use changes and human population dynamics on the carbon balance;
3) the quantification of the effects of climate and natural disturbances on the terrestrial carbon stocks and fluxes;
4) the application of new methodologies to investigate carbon metabolism at the plot, ecosystem and regional scale.

The project is organized in different tasks (Figure 2) trying to assess the contribution of the different components to the full carbon budget, like carbon stocks and fluxes from terrestrial ecosystems, disturbances (harvesting, wild forest fires and forest pathology), CH_4 and NO_2 fluxes and anthropogenic emissions. All these information will be inputs in a Data Assimilation System and the results will be validated using sub-regional airborne measurements of carbon fluxes. In this paper will be presented the methodologies that we are using in part of these tasks and some preliminary results.

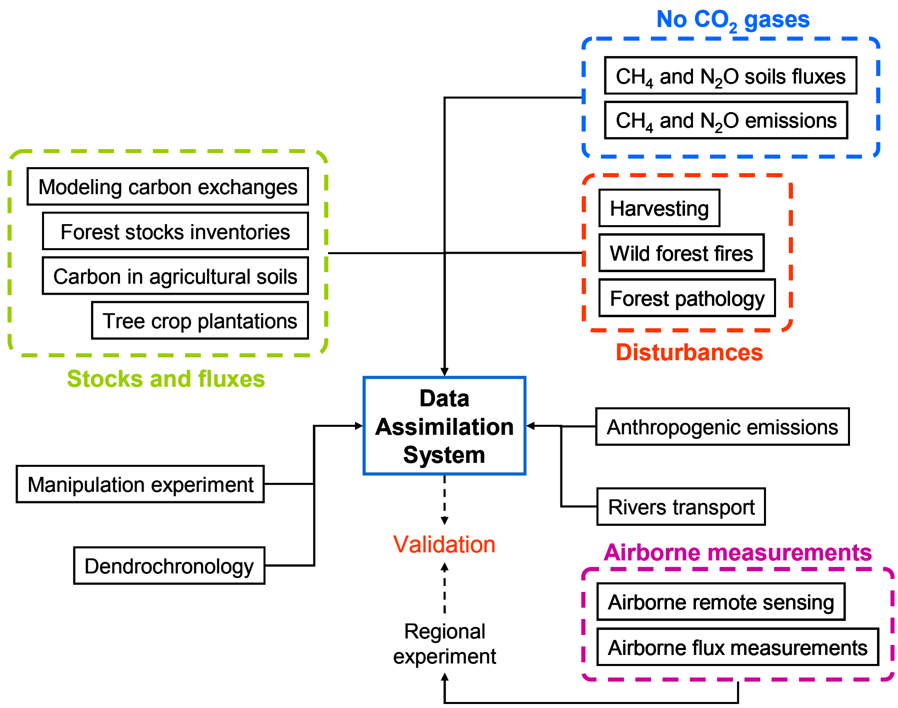

Figure 2: the CarbIUS project structure

2) GPP, Reco and NEP assessment using different model approaches

For a full carbon accounting the total carbon balance of the terrestrial ecosystems must be evaluated and not only some of it components. At the highest level of abstraction the net ecosystem exchange (*NEE*) which is defined as the net CO_2 flux into the atmosphere can be described as

$$NEE = GPP - TER$$

where *GPP* is the carbon uptake by photosynthesising vegetation, and *TER* is the terrestrial ecosystem respiration. TER can be split into the components heterotrophic (*Rh*) and autotrophic respiration (*Ra*), or above- and belowground, i.e. soil respiration. Most importantly it has to be noted that the above ground net primary productivity that is of interest in forest and agricultural economy, is different from the ecosystem carbon balance, since changes in belowground carbon pools often dominate the terrestrial carbon balance.
It is not simple to measure directly all the components described before, in particular for large scale analysis, and the only way possible to obtain an assessment of GPP, TER and NEE for large region like a country or a continent is to use ecosystem models.
It has been proven useful to classify ecosystem models along a gradient from data driven to process driven models. Date driven models typically do not contain internal dynamic state variables, but more or less directly relate relevant known variables (e.g. vegetation type, meteorological variables) to desired unknown quantities (e.g. carbon balance components). Typical examples are artificial neural networks, multivariate regression approaches and other techniques related to data mining (e.g. regression trees, state vector machines) (Papale and Valentini, 2003). On the other extreme lie completely process-driven models that explicitly represent all important state variables and processes of the studied system and only variables that are outside the system boundary are fed into the modelling system. This other extreme is hardly ever reached, since there are always state variables that are either prescribed or hold constant in terrestrial ecosystem models, but dynamic global vegetation models come

closest (Cramer et al., 2001), where both biogeochemical cycles (mostly carbon, nitrogen, and water) and vegetation distribution are described. Between the two poles of data and process-driven models spans a continuum of hybrid data/process driven models where model internal state-variables are partly replaced by external input and partly internally represented. Typical examples are various remote sensing driven models, that use derived dynamics of LAI/fPAR (in terms of models fPAR is a derived property from the state variable LAI), but internally represent other state variables like woody biomass and soil carbon pools. These kinds of models are more on the data-oriented side of the spectrum. Biogeochemical models like BIOME-BGC or DAYCENT are, according to this classification, hybrid approaches on the process-oriented side of the spectrum (since most of the state variables are represented internally, but e.g. not the distribution and dynamics of vegetation). The general characteristics of the different approaches are summarized in Table 1.

	Data Oriented Approaches DOA	**Process Oriented Approaches POA**
Advantages	Few parameters, flexible assumptions, computational efficiency, uncertainties easier to define	Possible attribution of sinks/sources to human activity, prediction/extrapolation possible, ecological interpretation
Major concern	Data precision and representativity (spatial, thematic)	Validity of process assumptions

Table 1: general characteristics of the different modelling approaches

In this project we used three different models to assess GPP, TER and NEE: Artificial Neural Networks that can be classified as strongly Data Oriented Approach, LPJ that is a complex Process Oriented Approach and MOD17+ that is a Remote sensing driven model and that can be classified as hybrid between DOA and POA approaches.

2.1) Artificial Neural Networks

Artificial neural networks are a fast expanding field that has applications in many fields, from natural science disciplines (physics, biology, chemistry, etc.) to socio-economic science (literature, language, social studies, etc.) (Bishop, 1995; Demuth & Beale, 2000). Neural networks have great potential in biology and ecology because they are able to represent the complexity of phenomena in examination (Lek & Guegan, 2000). Normally in such complex systems the manifestation of a function, or a property of the organism, represents the arranged effect of multiple nonlinear factors, which become activated to a given degree only in response to particular external circumstances.

To use ANNs you need a training and validation datasets, composed by both the inputs and the outputs that will be used to train the ANN. After the training process and the validation of the ANN using dataset not used in the training phase, it is possible to apply the network using only the input data (Figure 1).

In this case the inputs are meterogical variables like Incoming radiation, temperature and humidity, land use map and remotely sensed data and the output are NEE or GPP (Papale and Valentini 2003).

To have a measured output we are using data from Eddy covariance sites in Italy and Europe (Figure 2). In these sites, using micrometeorological techniques it is possible to measure the Net Ecosystem Exchange at high temporal resolution (half hour) in about 1km around the measurement point (Aubinet et al. 2000). Currently 20 sites are acquiring data in Italy and more that 100 in Europe (in the contest of the Carboeurope IP project, www.carboeurope.org) covering a large number of climate condition and land use classes. In this preliminary CarbIUS application the input data used were the same chosen for the MOD17+ application (see below).

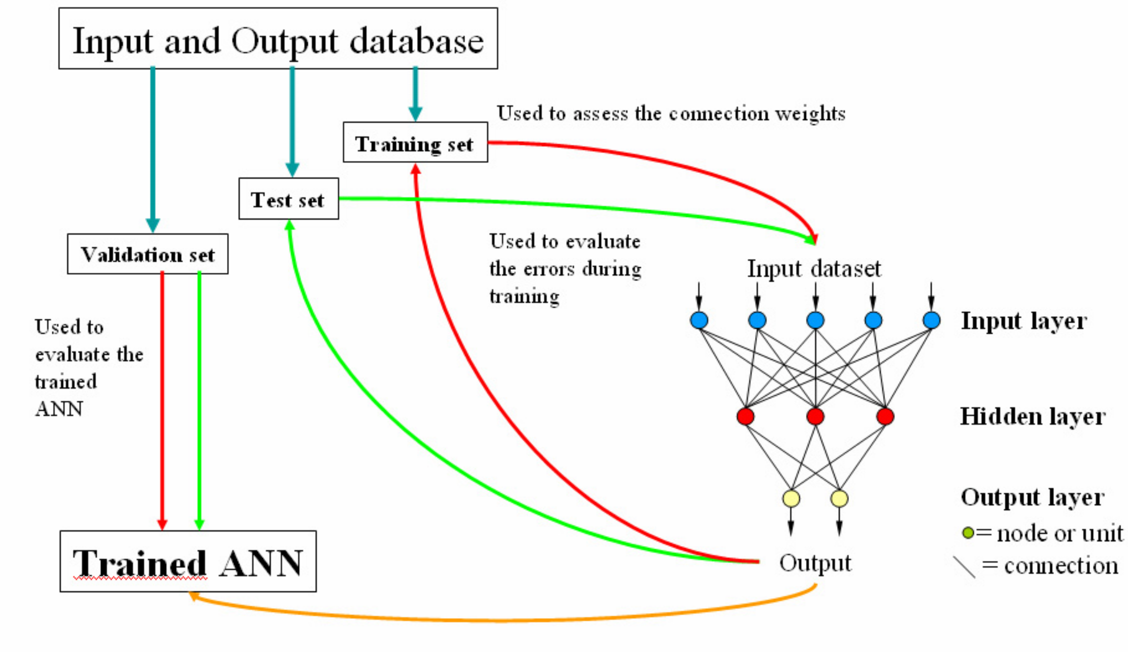

Figure 1: Training, test and validation of Artificial Neural Networks

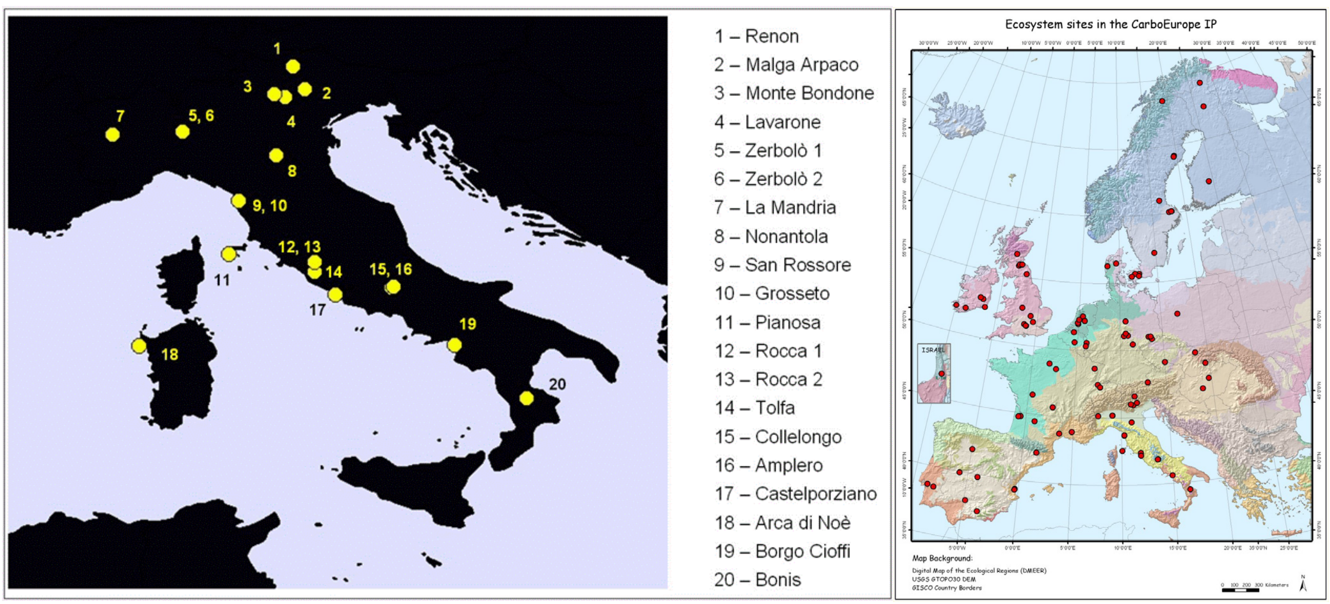

Figure 2: Eddy covariance sites in Italy and Europe (for more information: www.carboeurope.org)

2.2) MOD17+

An independent estimate of the regional carbon balance was obtained by applying a semi-empirical model of net ecosystem exchange (NEE) driven by MODIS fAPAR data. In this approach NEE is modelled as the difference of its main components (gross primary productivity, GPP, and ecosystem respiration, Reco): NEE= Reco – GPP.

The model structure for calculating daily average GPP is identical with that used for estimating global carbon fixation (Running et al., 1999; Running et al., 2000):

$$GPP = \varepsilon \cdot fAPAR \cdot PAR$$

PAR is the photosynthetically active radiation flux (MJ m^{-2} day^{-1}), *fAPAR* is the fraction absorbed by the vegetation, and ε is the conversion efficiency of energy to fixed carbon (gC MJ^{-1}) according to equation:

$$\varepsilon = \varepsilon_{\max} \cdot f_1(T_{\min}) \cdot f_2(VPD)$$

where $\varepsilon_{\max}$ is the vegetation specific maximum conversion efficiency. The functions f_1 and f_2 (between 0 and 1) describe the influence of meteorological conditions on ε with $T_{\min}$ being the daily minimum air temperature and *VPD* the daytime average vapour pressure deficit. While these functions were left as in the original parameterization the maximum radiation-use efficiency ($\varepsilon_{\max}$) was optimized vegetation-specifically against available European eddy covariance data from the CARBOEUROPE network (Reichstein *et al.*, 2003), excluding the Loobos site, that is used in a regional budget estimation.

Ecosystem respiration was estimated with a semi-empirical model modified from (Reichstein *et al.*, 2003):

$$R_{eco} = \left[R_0 + \left(1 - e^{-k_1 \cdot LAI_{\max}}\right) \cdot R_1 + \left(1 - e^{k_2 \cdot GPP}\right) \cdot R_2\right] \cdot e^{E0 \cdot \left(\frac{1}{Tref - T0} - \frac{1}{T - T0}\right)} \cdot \frac{P + P_0}{k + P + P_0}$$

Where LAI_{max} is the maximum leaf area index at the site [m^2 m^{-2}], GPP is the gross primary productivity [gC m^{-2} day^{-1}], T (°C) is the average air temperature, and P is the precipitation of the last 30 days (mm). The other quantities are parameter of the model describing the assumed functional dependency of the quantities. Compared to the previously published model on soil respiration (Reichstein et al., 2003b), a short-term dependency of Reco on GPP is added and the temperature dependency is changed from Q10 model to the Arhennius-type of equation. The parameters were derived using eddy covariance ecosystem respiration data that have been derived according to the methods in (Reichstein et al., 2004). As in the original model, in this analysis the parameters are assumed not to be vegetation specific and forest sites are overrepresented in the used eddy covariance data sets.

The necessary fields of meteorological data (PAR, Tmin, VPD) are taken from NASA's data assimilation office (DAO-GEOS 4 data) in the same way as for the calculation of the global MODIS GPP/NPP product (MOD17, see (Running et al., 1999b). The coefficients fAPAR are estimated from reflectance derived via an inverted radiative transfer model (Myneni et al., 1997) from the MODIS data stream (MOD15A2, version 004; see (Knyazikhin et al., 1999). Daily values of fAPAR are obtained by linear interpolation between the original values that represent the most reliable observation during an eight day period (Knyazikhin et al., 1999). Periods of cloudiness and times when the sensor is not working properly (indicated by a quality flag) are also filled by interpolation. The interpolation should not introduce significant errors since vegetation structure, particularly in evergreen forests, does not change much over periods of days to weeks. Finally, the fPAR time series were subjected to a treatment with the BISE algorithm with a window size of 2 time steps (Viovy and Arino, 1992), to remove occasional (less than 10% are the data) sudden spikes of MODIS fAPAR data likely caused by atmospheric effects not indicated by the quality control flag.

2.3) LPJ

LPJ DGVM (Smith et al. 2001, Sitch et al. 2003) is one of a family of models derived from the BIOME terrestrial biosphere model (Prentice et al. 1992). The model simulates the distribution of 10 plant functional types (PFTs) with different physiological (C3 or C4 photosynthesis), phenological (deciduous, evergreen), and physiognomic (tree, grass) attributes, based on bioclimatic limits for plant growth and regeneration and plant specific parameters that govern plant competition for light and water.

Photosynthesis is calculated as a function of absorbed photosynthetically active radiation, temperature, atmospheric CO_2 concentration, day length, and canopy conductance using a form of the Farquhar scheme (Farquhar et al. 1980,Collatz et al. 1992) with canopy-level optimised nitrogen allocation (Haxeltine and Prentice 1996b) and an empirical convective boundary layer (Monteith 1995) to couple the C and H_2O cycles. Soil hydrology is simulated using two soil layers (Haxeltine and Prentice 1996a).

Annual NPP is allocated to the four carbon pools (representing leaves, sapwood, heartwood, and fine-roots) of each PFT population on the basis of allometric relationships linking height, diameter and the leaf-area to sapwood area ratio to these pools (Huang et al. 1992, Shinozaki et al. 1964). Litterfall from vegetation enters separate above- and belowground litter pools, which themselves provide input to a fast and a slow decomposing soil carbon pool. Decomposition rates of soil and below-ground litter organic carbon depend on soil temperature

(Lloyd 1994) and soil moisture (Foley 1995). Fire fluxes are calculated based on litter moisture content, a fuel load threshold, and PFT specific fire-resistances (Thonicke et al. 2001). Vegetation dynamics are modelled based on light competition, fire disturbance, re-establishment rates, and a set of temperature-related limits to survival or establishment (Sitch et al. 2003).
The model application here is based on natural vegetation without farm equing systems. The model was spun up to equilibrium at 1900, and then run transiently with increasing CO_2 concentration and observed interpolated climate input from the Climate Research Unit (CRU).

3) Losses of carbon in forest due to disturbances
(contributions: A. Barbati, C. Belli, P. Calvani, G. Chirici, I. Palumbo)

3.1) Forest harvesting and wood utilization

Where forests are harvested for wood utilization, a fraction of the total NPP (NPP = GPP –Ra) is yearly removed from forest carbon stocks. It is important to highlight that what can be reasonably assessed based on available statistics on wood removals in Italy is the carbon yearly lost from forest carbon stocks due to forest harvesting (not CO_2 emission due to domestic wood consumption).
Technically, woodfuel combustion in modern stoves can achieve complete combustion, which means that all the carbon stored in the fuel is transferred into CO_2. However, in practice, not all woodfuel combustion takes place in efficient stoves (meaning higher CO/CO_2 emission); in addition woodfuel is not only represented by forest felling, trees outside forest and woodfuel import being also relevant sources (Italy is the first European importer of woodfuel, FAO, 2002).
At the same time is almost impossible to assess possible CO_2 emission from roundwood consumption, as most wood products are exported and the average life cycle of wood forest products can not be easily predicted.
The losses of carbon ($C_{woodutilization}$) from forests due to forest harvesting in each Italian Province at the year 1990 and at the year 2000 were assessed by the following algorithm:

$$C_{woodutilization} = HV \cdot k_1 \cdot bd \cdot k_2 \qquad [t]$$

where:
HV = harvested wood volume [m^3] per Province, according to official forest statistics by the Italian Agency for Statistics (ISTAT);
k_1 = average expansion coefficient to take into account the wood residuals left in the forest stands (cutting woody debris); this coefficient was set equal to 1.176, according to Corona and Nocentini (2002);
bd = average wood basal density of forest tree species in Italy, set equal to 0.65 t m^{-3}, according to APAT (2003);
k_2 = average carbon content per unit of wood biomass of forest tree species [t t^{-1}], set equal to 0.5 according to APAT (2003).

3.2) Forest fires

Forest fires are another source of emission of greenhouse gases. The existing inventories in the world (EDGAR described in Olivier and Berdowski, 2001a, GEIA (http://weather.engin.umich.edu/geia), Cooke and Wilson, 1996, Liousse *et al.*, 1996) are based on the relationship between the burned biomass and the emission flux, linked by an emission factor dependent on the combustion type and consequently on the burned vegetation type.
The method used for the emission calculation for the species *x* is based on the following equation given by Seiler and Crutzen (1980):

$$Q_x = M \cdot EF_x$$

where Q_x denotes the gas or aerosol emission flux, M the amount of burnt biomass and EF_x the emission factor given for the species x in grams of *x* per kilogram of dry matter (g *x*/kg dm).
A first estimate of the carbon removed from forest carbon stocks due wildfires ($C_{forestfires}$) was calculated for each Italian Province at the year 1990 and at the year 2000 by the following algorithm:

$$C_{forestfires} = BF \cdot BFB \cdot k_2 \qquad [t]$$

where:
BF = burnt forestland [ha] per Province, according to official statistics by the Italian State Forest Service (Corpo Forestale dello Stato);
BFB = average burnt wood biomass on burnt forestland [t ha^{-1}], elaborated from data provided for each Administrative Region by Bovio (1996), i.e., Valle d'Aosta, Prov. Bolzano, Campania, Puglia, Basilicata, Calabria, Sicilia, Sardegna = 13.5 t ha^{-1}; Prov. Trento, Veneto, Friuli V.G. = 15 t ha^{-1}; Piemonte, Lombardia, Liguria, Lazio, Abruzzo, Molise = 16.5 t ha^{-1}; Emilia Romagna, Toscana, Umbria, Marche = 18 t ha^{-1};
k_2 = average carbon content per unit of wood biomass of forest tree species [t t^{-1}], set equal to 0.5 according to APAT (2003).
However in this case we estimated the carbon removed from forest carbon stocks due wildfires ($C_{forestfires}$), but not CO_2 emission due to forest fires, as this depend on the type of wood combustion occurred: e.g. in an incomplete combustion C is emitted as CO_2, but also as CO and CH_4.
During the last decade, the characterization of the emissions has significantly improved. A series of experiments in Africa (SAFARI 1992, 2000, DECAFE 1988, 1991 and EXPRESSO, see http://ceos.cnes.fr:8100/cdrom-00b2/ceos1/casestud/burnbio/projects.htm) and in the US and Brazil (SCAR C, SCAR B, see http://asd-www.larc.nasa.gov/scar/) have allowed the determination of emission factors for many chemical species, as a function of the combustion mode, with good accuracy (Andreae and Merlet, 2001; Liousse *et al.*, 2003). Recent laboratory experiments were carried out at the Max Planck Institute (Mainz, Germany) for different fuel types ranging from central European to tropical vegetation; for the Mediterranean ecosystems (Greece) the emission factors of some species were also defined: aleppo pine (*Pinus halepensis*) and kermes oak (*Quercus coccifera*); (see EFEU Project at: http://projects.tropos.de:8088/afo2000g3).
Most of the uncertainty in emissions values now lies in the estimate of burned biomass (1) and in the temporal dynamics, namely seasonal and inter-annual, of this variable.
For our assessment biomass burned is defined as follow:

$$M = A \cdot B \cdot \alpha \cdot \beta \qquad (1)$$

where A is the burnt area (m^2), B the biomass density (g m^{-2}), α the fraction of aboveground biomass, and β the burning efficiency.
Parameters B, α and β vary with the particular ecosystem under study and are determined by assessing the total biomass before and after burning.
The burned area extension and distribution will be obtained from official statistical data by CFS Corpo Forestale dello Stato (http://www.corpoforestale.it): data are available for sub-regions and main vegetation type on a yearly basis. These information will be also integrated with remotely sensed derived data from airborne and satellite platforms; in particular, a validation of the burned areas extension assessed by CFS was performed during the last year in the Lazio region. Using an airborne multispectral camera we acquired images regarding all the fires occurred in 2004. The images were orthorectified and validate with ground GPS measurements. In table 1 is shown the difference between the two assessments (CFS and proximal sensing).

	Remote sensing (ha)	**CFS (ha)**	**% difference**
Total wooded burned area	2818.42	2108.75	+ 33.65
Total not wooded burned area	1258.36	1108.04	+ 13.57
Total	4076.78	3216.79	+ 26.73

Table 1: differences between burned areas estimated by CFS and using airborne remote sensing (source: the SIMIB project)

Burning efficiency, depending on burning conditions and environmental characteristics, will be studied more in detail both on ground level and through remote sensing techniques. When estimating emissions from biomass burning, burning efficiency is a critical parameter, which needs improvements. The analysis will focus on fire severity which will provide information about combustion completeness; biomass measurements will be collected in the field and will be used to find correlation with spectral indices (e.g. NDVI, relative greenness, SR..) from satellite images at high spatial resolution (e.g. Quickbird, Landsat TM). Emission factors derived from Andreae and Merlet (2001) will be integrated with the laboratory experiments carried out at the max Planck Institute.

3.3) Models to estimate the CO_2 losses due to pathogens

Efficiency of carbon fixation through forestry depends on several factors including the losses of biomass due to abiotic and biotic stresses. As an example, these losses have been estimated for the Oregon Washington region in 403 million of cubic feet corresponding to 13% of the total annual growth (Anonymous, 1967. Annual losses from diseases in Pacific Northwest forests. USDA Forest Service Bulletin PNW 20).

Estimation of biomass losses from diseases is not an easy issue since the data available are not homogeneously distributed, surveyed by different methods and then difficult to compare.

Furthermore the scarce definition of land use data in Italy makes more difficult an accurate estimation of losses based on forest typologies.

The objective of the present contribution is to offer some examples of CO_2 losses estimation in Italy due to specific diseases at county (province) level using different approach and source datasets. The study-cases regard the estimation of CO_2 losses due to Ink disease of chestnut in Central Italy in the Rieti province, and to *Heterobasidion annosum* on *Picea abies* in the province of Udine in Northern Italy.

As it will be illustrated below, the estimation of losses due to pathogens was carried out by different techniques and expressed at province level. However results obtained for each forest typology was verified by comparison with sources of data and values obtained with a different methodology.

The total amount of CO_2 calculated is referred to the whole volume of the infected trees. Of course the effective value of CO_2 lost will depend on the utilization of the infected trees. In some cases they are left standing in the forest because their removal is not economically convenient. However part of this biomass could be utilised in the wood chain (chips, low quality product) or as source of energy.

3.3.1) Chestnut ink disease caused by the root collar rot pathogen Phytophthora cambivora

Main source of data was represented by a regional project PRAL 1999/2001 - Progetto codice 2002/28 on estimation of incidence of Ink disease of chestnut based on remote sensing, GIS applications and “ground activities”.

In Figure 1 the Ink disease affected area (light blue) is overlapped to the chestnut distribution area (brown) monitored (about 832 hectares). Number of affected trees within the infected area was estimated in transects by “ground activities” according to and arbitrary visual scale. Number of trees per hectare and the volume of the model tree were estimated by interview to local owner and harvesting companies. Consistence of chestnut cultivation in the province of Rieti was obtained by the ISTAT bulletin.

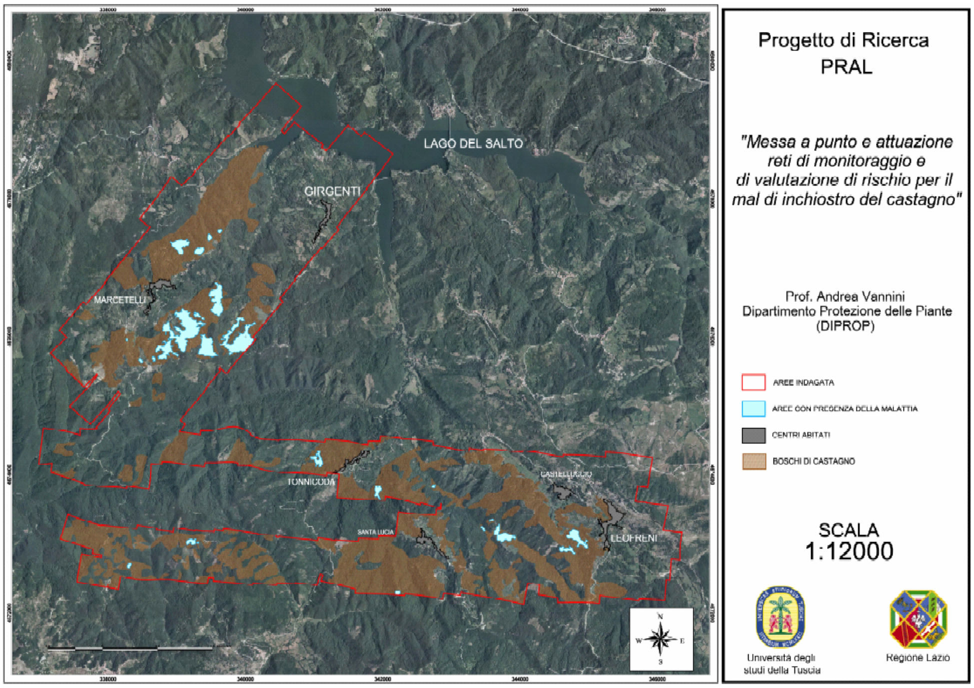

Figure 1. Chestnut distribution in the investigated area. The Ink disease infected areas are represented in light blue colour.

Average volume per hectare (120 trees per ha, 2 m^3 biomass volume per tree)	240 m^3/ha
Total chestnut biomass in the Rieti Province	**955440** m^3
Total chestnut area monitored with the PRAL project 1999/2001 - 2002/28	832 ha
Total biomass of the monitored area	**199675** m^3
Chestnut area affected by Ink disease within the total monitored area	58 ha
Total biomass of the affected areas	**13920** m^3
Percentage of diseased trees within the affected area	47%
Biomass lost for Ink disease within the affected areas	**6542** m^3
Percentage of the losses calculated over the biomass of the monitored area	(**6542**x100)/**199675**=3,3%
Estimated losses on the total chestnut biomass in the Rieti province (3,3% of **955440**m^3)	**31530** m^3
CO_2 lost for the Rieti Province (Specific density chestnut dry wood: 0.53 g cm^{-2})	**30581** t CO_2

Table 1. Methodology used to estimate the CO_2 losses due to chestnut Ink disease

The estimated data, and specifically the percentage of infected trees by Ink disease (3,3%) was verified by comparison with the value calculated within the EC project CASCADE by the assessment of 621 trees in 23 plots distributed in Italy and corresponding to 5,9%.

3.3.2) Butt rut of red spruce caused by Heterobasidion annosum

Main source of data was represented by the Forest Health monitoring system of the Friuli Venezia Giulia region whose data-base is available in MS Access 2000 format (Microsoft) with some GIS applications. The information included in the data-base are reported in Table 2.

Forest Health Monitoring System of the Friuli Venezia Giulia region	**RECORD DATA-BASE**
	Year of record
	Forest district
	Pathogen
	Host
	Affected area (hectares)
	Percentage of defoliation or volume of biomass lost
	Other information

Table 2. Information included in the data-base of the Forest Health Monitorino system of the Friuli Venezia Giulia region

The biomass affected by *H. annosum* was estimated as the volume of the trees affected over the whole volume after clear cutting activities (Table 3).

Codice	Specie	Data rilievo	Comune	Volume del lotto	Piante colpite	Volume (mc)	% Volume perso
1997/005	Abete rosso	01/04/1997	Socchieve	699.600	60	76.25	10.899
1997/150	Abete rosso	30/07/1997	Forni Avoltri	1.154.800	162	98.00	8.486
1999/003	Abete rosso	10/04/1999	Arta Terme	980.000	164	249.00	25.408
1999/006	Abete rosso	14/04/1999	Socchieve	484.800	183	196.30	40.491
1999/014	Abete rosso	26/04/1999	Villa Santina	62.382	25	29.75	47.690
1999/108	Abete rosso	06/08/1999	Ligosullo	1.073.900	103	202.75	18.880
1999/143	Abete rosso	24/09/1999	Paularo	535.950	52	101.25	18.892
1999/152	Abete rosso	03/10/1999	Rigolato	610.280	79	40.00	6.554
1999/180	Abete rosso	12/11/1999	Paluzza	198.536	22	6.00	3.024

Table 3. Number and volume of the *H. annosum* infected trees assessed on the total volume after different clear cuts in the Udine Province. Volume del lotto = total wood volume, Piante colpite = trees infected, Volume perso = volume lost due to the pathogen.

The average percentage of lost volume by *H. annosum* attacks corresponds to 20±14,5. The total biomass of red spruce in the Udine province is estimated in about 5.800.000 m^3. The estimation of CO_2 losses was calculated as follow:

$$V' = V_{TOT} \cdot I = 5.800.000 \cdot 0{,}2 = 1.160.000 m^3$$

where:
V' = estimated red spruce biomass affected by *Heterobasidion annosum* ;
V_{TOT} = estimated total red spruce biomass of the Udine Province (database of the Friuli Venezia Giulia Region);
I = incidence (%) of *Heterobasidion annosum*.

$$M' = V' \cdot s.d. = 1.160.000 m^3 \cdot 400\, kg/m^3 = 464.000.000 kg$$

where:
M' = dry mass affected by Heterobasidion annosum
s.d. = specific density of dry matter of red spruce.

The amount of CO_2 lost by *Heterobasidion annosum* on red spruce was estimated with the formula of Bagnaresi et al. (1983)

$$464.000.000 kg \cdot 1{,}83\, kgCO_2/kg = 849.120.000 kgCO_2 = 0.849 MtCO_2$$

The estimated data, and specifically the percentage of infected trees by *Heterobasidion annosum* on red spruce (20±14,5 %) was verified by comparison with the value calculated by Anselmi e Minerbi (1989) corresponding to the range of 9,5-42,9%.

4) CO_2 emission from agricultural soils

4.1) General objects of the research

The 46- 49% of total national emissions of CH_4 e N_2O (GHG) comes from agriculture practices. The 17% of these emissions derives from Soil Organic Matter (SOM) degradation.

The contribution of Agriculture to the increase of atmospheric CO_2 is known, but until now no official data are available.

The aim of the study on agricultural soils, in the framework of project CarbIUS, is:

1. to determine the budget of the soil organic matter in agricultural soils on national scale for years 1990 and 2000. The actual amount of soil organic matter is determined through the evaluation of the contributions and it removes (due to mineralization, erosion and leaching);
2. to assess the contribution of soil respiration to the total emission of CO_2 in the atmosphere. The objective, well inside the study of the total emissions of greenhouse gases, is to verify the engagement of Italy in the Kyoto protocol to reduce of 6.5% the emissions of CO_2 within 2012 respect 1990 (deliberation CIPE 137/98).

4.2) Methodologies and techniques utilised

The present study involves two phases:

1. production of a database from literature for the years 1990 and 2000 collecting the main parameters that influence organic Carbon's budget in the soil and concerning all Italian provinces.
   In particular:
   - climate (temperature, rainfall);
   - soil texture;
   - irrigations;
   - fertilizers;
   - crop rotation;
   - pesticides;
   - input of soil organic matter and total N;
   - management of the agricultural wastes: burning, removed, buried;
   - land use and management: intensive, mixed, vegetables, wood cultivation, etc...
2. use of data in a statistical-mathematical model, CENTURY v.5, to obtain the evaluation of input and output of soil organic matter and estimate the flow of CO_2 during the decade.

4.3) Constrains

Availability and heterogeneity of bibliography data to be utilised in Century Model are producing some problem.

Each Italian region or province utilise different instruments to study agricultural soils and climate leading to non homogeneous scales and parameters manly on soil organic matter content, soil chemical and physical characteristics and water quality.

This problem mainly exist in data related to the year 1990, while for the year 2000 we detected a general higher attention of publics and privates research agencies on agricultural soils.

The agricultural landscape in Italy changed from 1990 to 2000: it decreased due to different uses, mostly for building trade and for the conversion from agricultural land to forest land after CEE 2080/92 act. Consequently total agricultural land decreased of 2 millions of hectares. Furthermore, after CEE 2078/92 act, that promoted the organic agriculture, 2 millions hectares have been converted from conventional to organic and integrated management.

It is likely that an eventual important change of total emission of CO_2 from agricultural soils occurred after the change of land use.

4.4) First results

The first results of this study show the average of CO_2 emission from agricultural soils of two Italian regions: Piemonte (North Italy) and Sicilia (South Italy), obteined from simulations with Century Model version 5. The results are ordered for provinces and for year.

	Cereals and vegetables		**orchards**		**Vine**		**grassland**		**Average**	
	1990	**2000**	**1990**	**2000**	**1990**	**2000**	**1990**	**2000**	**1990**	**2000**
Piemonte	**1,23**	**1,27**	**1,36**	**1,38**	**1,09**	**1,31**	**1,37**		**1,22**	**1,26**
Alessandria	1,20	1,08					1,44		1,32	1,08
Asti	1,11	1,19			0,75	1,48			0,93	1,34
Cuneo	1,37	1,33	1,36	1,38	1,10	1,64			1,28	1,45
Torino	1,25	1,43				0,80	1,29		1,27	1,11
Vercelli	1,22	1,32			1,41				1,32	1,32
Sicilia				**1,24**				**2,44**		**1,41**
Catania				0,47						0,47
Messina				1,42				2,44		1,93
Agrigento				1,82						1,82

Table 1: CO_2 produced from soil respiration for provinces of Piemonte and Sicilia regions (t/ha)

year	**management**	**CO_2 emission (t/ha)**
1990	conventional	1,23
	organic	-----*
2000	conventional	1,25
	organic	1,00

Table 2: CO_2 emission from conventional and organic management for all Century simulations (t/ha)

*organic agriculture was still at the start.

Preliminary results for the Piemonte region showed that the CO_2 emissions per hectare, on average, increased in the year 2000 with respect to the year 1990 also if in the Alessandria and Cuneo provinces there were a decrease of the emissions per surface unit in cereals and vegetables, a cultivation type very important in these two province with more than 267000 ha, about the 25% of the agricultural areas; Sicilia region data, for the moment, for the year 1990 are not available. Nevertheless, the comparison between the two regions for the year 2000 showed higher values for Sicilia, in agreement with the different climatic conditions (*continental* for the North Italy and *mediterranean* for the South) and the different soil organic matter content (much higher for Piemonte). Moreover, CO_2 production is lower in organic land management in the year 2000 in comparison to the conventional use (Table 2). In general data suggest that soils between 1990 and 2000 worked as C source instead of C sink.

5) National Budget of N_2O and CH_4 from agricultural and natural ecosystems

N_2O and CH_4 are greenhouse gases with a Global Warming Potential 62 and 275 times that of CO_2 (IPCC, Climate Change 2001, 20 year horizon). Differently from CO_2 emissions, for which a significant contribution to the budget of each industrialized country comes from anthropogenic activities, N_2O and CH_4 net emissions mostly depend on biological process which occur in soil. Data of fluxes of N_2O and CH_4 are quite abundant for both agricultural and natural ecosystems of the Central-Northern part of Europe, whereas data in the Mediterranean basin are scanty, as well as for other region characterized by Mediterranean climate (Castaldi et al. 2005). This makes the task of scaling up site fluxes to landscape level not really meaningful for the Italian region, hence necessarily, a modelling approach has to be used.

5.1) Methodology

With the exception of wetland, CH_4 consumption in most of the Italian land could be modelled at using a diffusive model in aggregated media (Potter et al., 1996). The modelling will be carried on in an implemented GIS environment (IDRISI), where extra modules (Piton language) will be created for the specific task. The input variables are presented in a raster format. Some layers are directly derived from available sources: metereological data from MARS project, soil characteristics from the Soil Regions (JRC), land cover from CORIN project. Other input variables have been calculated as a “reclass” based on available soil properties and known soil characteristic associated to such properties from literature data (e.g. total soil porosity has been derived from texture properties and information from Saxton et al. (1986). Other layers (e.g. CH_4 consumption rate/cm soil depth) have been created based on literature data and soil available characteristics. When soils were located in agro-ecosystems CH_4 consumption fluxes have been calculated from the diffusive model and decremented by a 40% based on literature data analyses (Castaldi et al., 2005). Due to the very small surface area covered by wetlands and rice paddies in our country, fluxes of CH_4 from these ecosystems have been derived using land cover surface (CORIN) and emissions factors published by Simpson et al. (1999).

Two different approaches will be used for N_2O emissions from agricultural and from natural ecosystems.

For the estimate of N_2O emissions (EN_2O) from agricultural soils a modified IPCC methodology (IPCC 1997) has been used. Direct and indirect emissions are calculated as follow:

$$\mathbf{EN_2O} = \mathit{EN_2O\ direct}\ (\text{fertilizers + histosols + crop residue + grazing}) + \mathit{EN_2O\ indirect}\ (\text{deposition + leaching})$$

Data related to the agricultural local practices were derived from National database (ISTAT) at a “region” level of aggregation (ex. major crops, fertilizers use as quantity and type, crop yields, area covered by crop type, number of different types of animals, etc.). Other data such as percentage of N in the excretion products of different animals were obtained by default values (UNESCO-FAO). When the quality of data allowed for a modelling geo-referenced approach N losses were calculated using a model rather than default emissions factors derived by IPCC from published information. This is the case for NH_3 and N_2O and NO emissions as well as leached N. These will be modelled in a GIS environment using geo-referenced environmental data described for the CH_4 model, geo-referenced agricultural data (e.g. Fertilizer-N/ha) derived from local agricultural practices information and land cover data (CORIN). The applied models are empirical relationships based on the analyses of published data proposed by Bowman et al. for the different N losses (Bowman et al. 2002a, 2002b, 2003).

N_2O emissions from natural ecosystems will be calculated using a biogeochemical model (Century) implemented to give N_2O emissions as a model output. The model will use input variables from a GIS environment and will produce geo-referenced N_2O emission values. Environmental data sources will be the same described for CH_4 model. Data related to vegetation will be derived from literature based on the main vegetation association expected in the Italian region on the base of land cover and altitudinal data available in geo-referenced format.

5.2) Results

A first preliminary calculation of N_2O emissions from agroecosystems was obtained by applying the IPCC procedure base on emission factors and default value provided by IPCC (Figure 1). The obtained value for year 1990 and 2000 were 68.35 Gg N_2O/yr and 66.35 Gg N_2O/yr, respectively, corresponding to 18,8 and 18,2 Tg of CO_2 equivalents. Considering the different source for year 2000, the direct sources (45.25 Gg N_2O/yr) of N_2O are twice the indirect sources (21.10 Gg/yr). A detail of the direct sources, given for the whole Italy in Figure 2. It can be noted that most of the emissions derive from crops management, although for certain specific regions such as Sardegna the contribution deriving from grazing makes almost 75% of the total direct N_2O emissions.

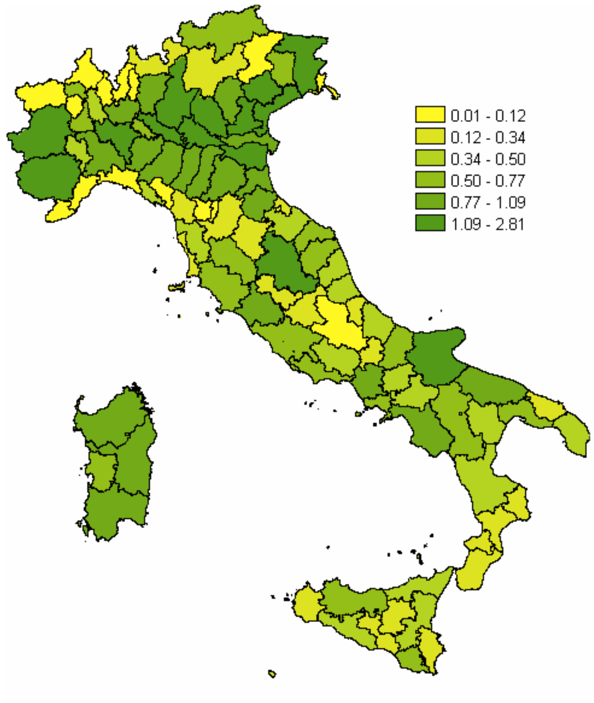

Figure 1: Total Gg N_2O emitted from agricultural soils in each region of Italy for the year 2000

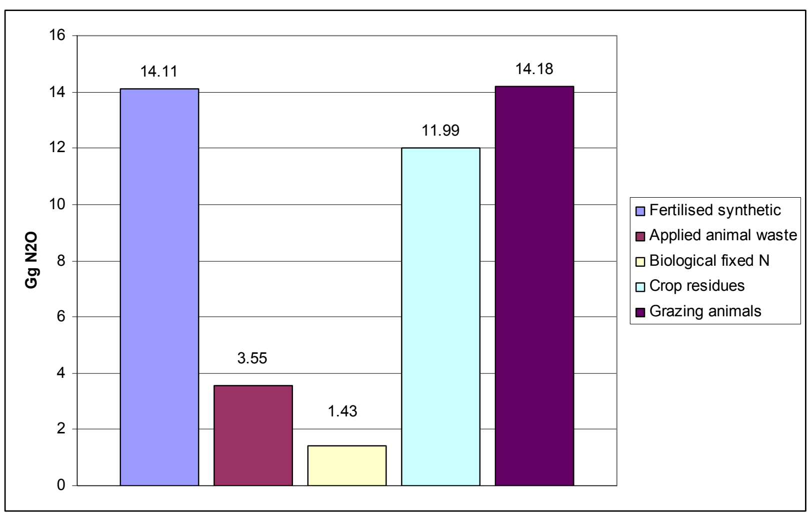

Figure 2: Gg N_2O emitted from direct source in Italy for the year 2000

CH_4 fluxes were estimated as a first approximation using an emission factor derived from few sample areas.
The total contribution to CH_4 uptake from natural ecosystem was 18.6Gg CH_4 yr^{-1}, corresponding to a removal of about 1.1 Tg of CO_2 equivalents from the atmosphere.
In agricultural areas the total sink of CH_4 is 14.46 Gg CH_4 yr^{-1}, corresponding to a removal of about 925 Gg of CO_2 equivalents (Figure 3). Assuming that in agricultural areas a 40% of reduction of the CH_4 sink is observed (Castaldi et al. 2005) the CH_4 sink would be about 24 Gg CH4 yr^{-1} if the agricultural areas were covered by original natural vegetation, corresponding to a CO_2 equivalent sink of 1.6 Tg.
To these values an approximate estimate of 6.1 Gg CH_4 yr^{-1} emitted from wetlands is given by Simpson et al (1999) for the Italian peninsula.

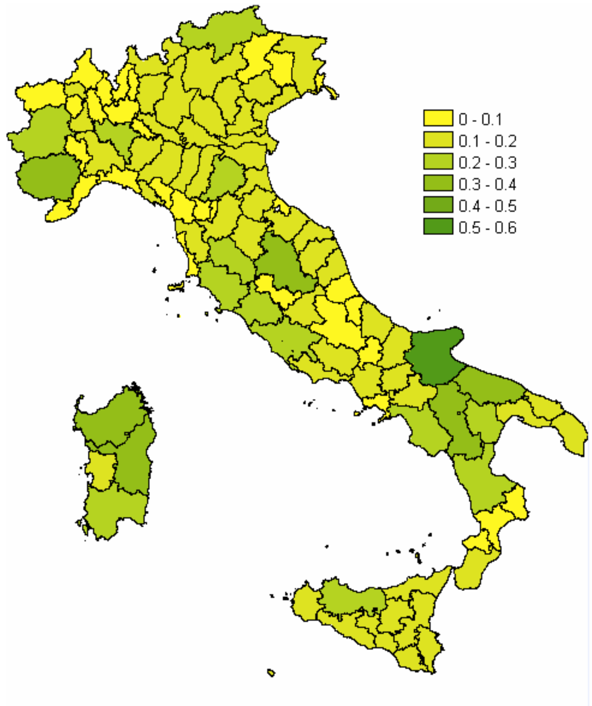

Figure 3: Gg CH_4 emitted from agricultural soils in each region of Italy for the year 2000

5.3) Main uncertainties and problems

Although the used models have been tested and validated by their authors, a first problem concerns the validation of results in this study with local data. The main limitation comes from the scarcity of N_2O and CH_4 flux data in our geographic area, which does not allow to compare different environments present in our country with modelled data. This probably remains as one of the future task to be carried out in this research field.

A big source of uncertainty derives from data quality. Concerning the database of environmental variables, very few Italian regions have detailed, geo-referenced and available information on soil characteristics, as well as meteorological data. Even bigger is the uncertainty on agricultural data for which no geo-referenced data exist and hence inferences based on statistical data and suggested agricultural practices have to be made. Finally uncertainty is also derived from the extrapolation of data on vegetation characteristics (e.g. above/below ground biomass) derived from literature to land cover typologies.

6) Biomass Carbon Stock change between 1990 and 2000 and NPP in permanent tree crops

According to the fifth National Census of Agriculture (ISTAT 2000) the area of permanent tree crops in Italy at year 2000 amounted to 2,458,941.11 ha with olive grooves and vineyards making up for 73% of total area (Table 1). A sharp decrease of 11.8% has occurred since 1990 when the fourth National Census of Agriculture (ISTAT 1990) reported a total tree crops area of 2,787,915 ha. During the same period total utilized agricultural area decreased of 12.3%. It is almost impossible at the national level to tell whether permanent crop area loss is due to a land use change towards other agricultural uses or non-agricultural uses. A better insight could be reached analysing the different crops at the most disaggregated spatial scale as possible.

type	*area (ha)*
Vines	717 333.78
Olives	1 081 255.17
Citrus	132 566.41
Other fruits	498 405.64
Nurseries	21 519.90
TOTAL	**2 458 941.11**

Table 1: Permanent tree crops in Italy (2000)
Source *Istat, 5° National Census of Agriculture*

Within the heterogeneous system of permanent tree crops in Italy, several complex dynamics have characterised this inter-census period (1990-2000). Olive growing is the most traditional sector within the tree crops system and the implementation of innovations has always been a difficult and slow process. As well as viticulture, olive growing has been profiting for a long time by a sort of protection allowed by the European Union to typical products (DOP, DOCG, IGT). As a result olive grooves area has remained almost constant in the inter-census period. Viticulture has experienced great changes during the last 20-25 years due to innovations of cultivation techniques but also to the introduction of new cultivars or the recovery of old very local and almost disappeared ones. The decrease of total vineyard area between 1990 and 2000 is the net result of the decrease of area for common wines production and the increase of the area invested for high quality wines. Citrus orchards area has decreased as well as other orchards area (apple, pear, peach, nectarine, etc.).
This general reduction of the area invested in permanent tree crops has been balanced to some extent by the more intensive techniques adopted in the remaining orchards. Generally higher stocking densities have been adopted in the new plantations. This has required the use of dwarfing rootstocks that are able to induce more tolerance to space competition.

6.1) Permanent tree crops and carbon

Permanent tree crops have recently gained interest in the sector of energy production because of the important amount of pruning residues they annually produce. The biomass resulting from explantation of orchards has received less attention maybe because it becomes available at the end of rotation i.e. at longer time intervals. Nevertheless carbon is stored in long living biomass for generally more than 15 years and in olive grooves for more than 80 years. Additionally soil organic carbon is reported to increase when shifting from annual to permanent crops in particular when less intensive soil management systems are adopted.
Undoubtedly the carbon stored at the single orchard level is bound to increase within a given time interval unless is explanted. During the same period, at whatever broader scale, the accounting of carbon is more difficult because some orchards could be explanted and not necessarily replanted or not necessarily with the same species.
Once the carbon stock variation in the system is assessed (which is not an easy task) the carbon costs of the management should be addressed i.e. energy inputs from outside the system.
In this chapter the preliminary results of an assessment of carbon stock changes in biomass of tree crops in Italy between 1990 and 2000 are reported. This study is based on data from literature and statistics at the national level and disaggregated at the province level. As the study is still in progress and is being carried out species by species, only the apple (*Malus domestica* Borkh.) grooves will be dealt with here at the level of the Province of Trento, one of the most important apple producing area in Italy.

6.2) Materials and methods

6.2.1) Carbon stocks

A thorough survey of the existing literature on apple has been carried out trying to find and/or derive as much information as possible on apple tree and apple orchard growth mainly in Italy. These data have been included in a database.
No papers dealing with biomass of apple trees or apple grooves have been found.
All the research papers dealing with the effects of density, cultivar, rootstock, trellis, pruning, on fruit production include average stem cross sectional area (measured at ca. 20 cm above the grafting point i.e. the connection of the scion with the rootstock) and age of the experimental plots. Stem diameter has been derived from stem cross sectional area. To date, 465 couples of diameter-age data are included in the database. In 56, 57, and 415 cases of

465 also the mass of material removed by winter pruning, mean tree height, and fruit production per plant were available respectively.
For each age, (from 0 to 16 years) mean stem diameter has been calculated, then diameter growth has been modelled using the logistic equation by Verhulst (Figure 1) (Kiviste et al 2002).

$$y = \frac{16}{(1 + e^{(1.94 - 0.266 \bullet age)})} \qquad \textbf{(1)}.$$

Because no data on tree biomass or tree volume were available in literature, a volume index given by the product of basal area and tree height has been chosen to have an estimate of tree volume. Fifty-seven volume indexes could be calculated (only 57 couples of diameter-height data were available). Volume index has been then expressed as a function of basal diameter. This has been accomplished by fitting the data with the logistic equation by Verhulst:

$$y = \frac{0.15}{(1 + e^{(5.8 - 0.43 \bullet diameter)})} \qquad \textbf{(2)}.$$

The area of apple orchards in Italy and in the Province of Trento in 1990 and in 2000 has been taken from the National Census of Agriculture of 1990 and 2000, respectively.
The National Institute of Statistics (ISTAT) produces a report on the major tree crops in Italy every five years. For the purposes of this study, three of these reports have been considered: 1992, 1997, and 2002 (ISTAT 1992, 1997, 2002). These reports give the distribution of total area for each species into age and density classes.
The same kind of distribution for the two target years (1990 and 2000) has been inferred by allowing transition of area from one class to another according to the change in age. In this way the total area does not change as only its partitioning into age classes varies. This means that the method per se does not take into account for explantations and new plantations. In fact such data were not available.
The area of each age class has been forced to sum into the total area reported for the two target years by the corresponding two censuses. By doing so it has been possible to "automatically" take into account for new plantations and explantations.

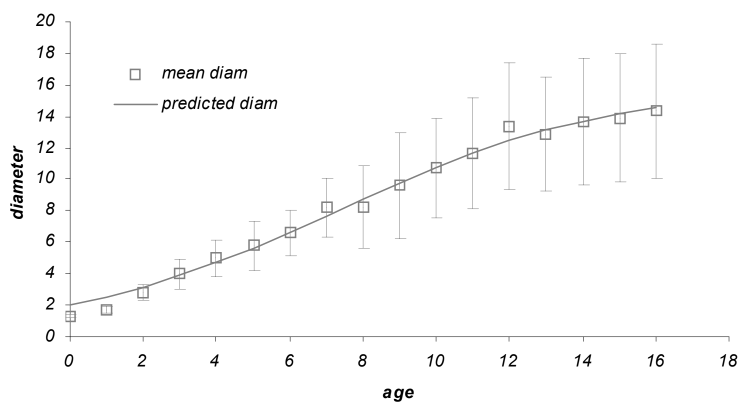

Figure 1: Diameter growth with age as modelled by logistic equation (vertical bars are standard deviation)

Using the central value of each age class the mean diameter has been calculated using equation (**1**) and the volume index relative to the mean tree at that age has been estimated using equation (**2**).
For a given age class, total volume index for each year is the product of mean volume and number of trees per hectare in the corresponding year. Using a basic density of 0.528 and a mean carbon concentration of 50% an estimate of the carbon stocks is obtained.

6.2.2) Net Primary Productivity in 1990 and 2000

A rough estimate of the net primary production for the apple grooves of Trento in the two target years was achieved by using apple fruit production for 1990 and 2000 (ISTAT 1990, ISTAT 2000), an estimate of pruning residues based on a regression with fruit production per plant, and the per cent allocation of total dry matter production into tree compartments (fruits, leaves, wood) derived from literature.

The regression of pruning residue per plant vs fruit production per plant has been built using 56 paired data (Figure 2). The fruit production per plant has been calculated dividing the total apple production by the number of plants in the province for the same year. Total apple pruning residue for the province has been transformed into carbon assuming a humidity of 45% and a carbon concentration of 50%.

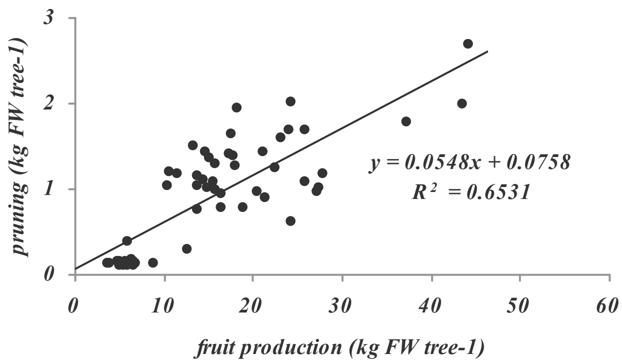

Figure 2: Linear regression of pruning material vs fruit production. Data are referred to single tree

As pruning is and annual practice, pruning residue is assumed to be produced annually by the plant.

According to Forshey and McKee (1970) the annual dry matter production is allocated differently in 'small' and 'large' trees. This means that trees with less vigour (e.g. cultivars grafted on dwarfing rootstocks or trees) tend to have more structural wood relative to fruit bearing wood than do small trees.

Small trees of the 'McIntosh' cultivar are reported to allocate 77%, 8.5%, and 14.5% of their dry matter production to fruits, leaves, and wood, respectively. Large trees of the same cultivar are reported to allocate 46%, 14%, and 41% of their dry matter production to fruits, leaves, and wood, respectively (Forshey and McKee, 1970).

In young 'Golden Delicious' grafted on MM106 (semi dwarfing) and cultivated in large pots, Heim et al. (1979) found that fruit dry matter accounted for up to 70% of total annual dry matter production and allocation to leaves ranged from 17%, on defruited trees, to 12% on trees with the highest crop load. This partitioning is closer to that of the 'small' rather than the 'large' tree of Forshey and Mckee (1970).

The percentages chosen to estimate the NPP of the apple orchards of Trento are those relative to small trees for 2000 and those by Heim et al. (1979) for 1990 because the average number of trees per hectare has increased by about 360 units from 1990 to 2000, which indicates a probable decrease in the average tree size. The resulting NPP estimates are driven by 'fruit' production. A humidity of 84% and a carbon concentration of 50% have been assumed for fruits.

The NPP estimated as above is relative only to the area in production, which was 96% and 92% of the total area in 1990 and 2000, respectively.

6.3) Results and discussion

The total area of apple grooves has slightly decreased between 1990 and 2000 (Table 2). The oldest age class has decreased by 47% indicating the tendency towards shorter cycles which is consistent with the decreasing of plant vigour achieved through the use of dwarfing rootstocks (M9 is the most used) which enables the growers to invest more plants per unit area and to shorten the unproductive juvenile phase.

Age[1]	*area 1990 (10^3 ha)*	*n° trees ha^{-1} 1990*[2]	*area 2000 (10^3 ha)*	*n° trees ha^{-1} 2000*	*mean diam (cm)*	*mean tree vol (m^3)*	*tot volume 1990 (10^3 m^3)*	*tot volume 2000 (10^3 m^3)*	*basic density*	*Cstock 1990 (MtC)*	*Cstock 2000 (MtC)*
2.5	2.16	1472	2.3	1427	3.5	0.002	5.9	6.6	0.528	**0.0016**	**0.0017**
7	2.4	1122	2.7	1428	7.7	0.011	31.1	43.9	0.528	**0.0083**	**0.0116**
12	1.9	789	2.1	1300	12.4	0.058	86.3	161.6	0.528	**0.0228**	**0.0427**
19.5	2.6	579	3.3	1051	15.4	0.104	158.5	360.4	0.528	**0.0418**	**0.0952**
35	3.2	403	1.7	492	16.0	0.112	143.0	93.2	0.528	**0.0377**	**0.0246**
sum	12.3		12.1							**0.1122**	**0.1758**

Table 2: Estimate of carbon stock in the apple grooves of the Province of Trento in 1990 and 2000
1: the central value of each age class has been used for calculations
2: the number of trees per hectare reported is the weighted average of the different density classes

The carbon stock estimated by means of volume index is increased from 0.112 to 0.176 Mt C despite the decrease in total area. The main reason is the increase in the number of plants. The algorithm used to estimate the volume index is density-independent, because it is based on a database built with data gathered from different experiments at different densities. On the other hand, up to now there are not enough data to build at least two different algorithms for two density levels.

The mean annual increase of carbon in the biomass stock is 0.006 Mt C yr^{-1}, which corresponds to 0.52 t C ha^{-1} yr^{-1} stored in wood, excluding the pruning material.

The estimated NPP (Table 3) is 0.037 and 0.095 Mt C yr^{-1} in 1990 and 2000, respectively.

The NPP per hectare is very low in 1990 and high in 2000: 3.17 and 8.52 t C ha^{-1} yr^{-1} respectively.

This difference could be in part explained by less favorable climatic conditions in 1990 compared to 2000. Fruit production in the former year was 33% lower than in the latter. Additionally, the age structure of the apple grooves in the two target years was quite different: more old plantations (>25 years) were present in 1990 than in 2000 (Table 2).

The majority of annual NPP is lost by the system via harvest and pruning (84% in 1990 and 85% in 2000). The portion of NPP that increases the carbon stock through time is wood, (stem, branches older than 1 yr, coarse roots) excluding pruning residues. This portion was 0.14 t C $ha^{-1}yr^{-1}$ in 1990 and 0.59 t C $ha^{-1}yr^{-1}$ in 2000, if the simple average of these figures is taken, a mean annual increase of carbon in the biomass stock of 0.36 tC ha^{-1} yr^{-1} is estimated for the decade of interest. This figure is 31% lower than 0.52 t C ha^{-1} yr^{-1} calculated as the difference of the carbon stocks of the two target years.

The pruning residue amounted to 0.005 Mt C yr^{-1} in 1990 and to 0.007 Mt C yr^{-1} in 2000. The average residue production for the decade is 0.006 Mt C yr^{-1}. Assuming that carbon concentration is 50% and humidity 45%, the total production of pruning material for the province of Trento amounts to 0.022 Mt C yr^{-1}. This figure is 46.8% of the estimate for Trentino-Alto Adige region according to Di Blasi et al. (1997) while the area of apple orchards of Trento is about 42.1% of the total regional.

Based on the simple average of the data derived from literature and included in the database (n=75) pruning material per hectare (fresh weight) resulted to be 2.8 t $ha^{-1}yr^{-1}$ (standard error 0.24) which is quite close to the national average of 2.4 t $ha^{-1}yr^{-1}$ reported for apple orchards by Di Blasi et al. (1997). The two estimates correspond to 0.56 and 0.48 t C $ha^{-1}yr^{-1}$, respectively.

	1990 (tC)	*2000 (tC)*
fruits	20332.00	61100.00
pruning	3579.22	5365.82
wood	249.54	6140.02
leaves	2244.44	6744.81
TOT	26405.19	79350.65
NPP ha^{-1}	2.15	6.57

Table 3: Estimate of NPP

6.4) Uncertainties

As for every estimate of carbon stocks and fluxes, in particular when referred to a broad scale, uncertainties are numerous and most of them are not easy to quantify.

As far as apple orchard area is concerned there are three sources: 1) the National census of agriculture, published every 10 years; 2) the yearbook of statistics in agriculture, published every year, based on sampling procedure; 3) the report of the structure and production of the main permanent tree crops based on sampling procedure. All are issued by the National Institute of Statistics and the data show slight differences when referred to the same year. We used as main reference the data from 4th and 5th National Census of Agriculture (NCA) in order to be consistent with the other studies presented in this paper. Data on crop production come from the 1990 and 2000 yearbooks but are corrected for differences in apple grooves area with respect to the NCAs of the corresponding years.

Because of the lack of data on literature about the biomass, a volume index (the volume of the cylinder with the same base and height of the tree) multiplied by basic density has been used to estimate the standing stocks of carbon (wood). This is probably a source of under estimation of the entire tree biomass, in particular, and this is the case, when roots are included.

Thus, the figures given here on carbon stocks are to be viewed as the minimum acceptable estimates.

The algorithm used to estimate NPP has proven to be very sensitive to the percentages adopted to ‘expand’ fruit production to total dry mass production. These percentages do not take into account fine root production and so do our estimates of NPP. This is another source of under estimation.

Because there were not enough data to build different algorithms for different densities, the growth equations are not sensitive to plant stocking. The sign of the error depends on the densities of the plots included in the database with respect to the real mean density of the orchards in the province of Trento. Average density was 812 and 1172 trees ha^{-1} in 1990 and 2000, respectively and the average density from the database was 1221 trees ha^{-1}. This means that trees in the database probably had smaller size than those in the two target years because of the higher density.

6.5) Conclusions

The carbon stocks in the apple orchards increased from 0.112 to 0.176 Mt C despite the slight decrease in total area. The annual increase in stocks is rather small due to the high intensity of the management systems that shift most of the annual production to fruits.

Another important component of NPP leaves the system via pruning practice and a total of 84-85% of NPP does not account for any increase in carbon stock.

The estimated NPP is rather low in 1990. There are several possible reasons for this: climatic conditions, age class composition and the method used to expand fruit production to total plant production. Nevertheless the assumptions underlying the method of estimation are quite reasonable.

Net Primary Production estimates do not include fine root production ant this could be an important source of under estimation. Due to their high turnover rate, fine roots do not generally contribute to any important increase in biomass from one year to the other but their contribution to soil organic matter could be important.

7) Validation of regional Net Ecosystem Exchange
(contributions: B. Gioli, A. Zaldei)

7.1) NEE measurement using a flux aircraft

One of the objectives of CARBIUS is to provide extensive and robust validation of regional NEE estimates that are made using the different methodologies that are discussed above. For this, an innovative approach is being used that involves the use of the flux aircraft Sky Arrow ERA (Environmental Research Aircraft) that is operated by the Institute of Biometeorology of the National Research Council of Italy.

The idea of using aircraft to measure gas exchange between the land surface and the atmosphere was developed more than 20 years ago (Lenschow et al. 1981, Desjardins et al, 1982). Airborne eddy flux observations with modern instruments properly installed and operated on appropriate aircraft may give results no less accurate than from a careful flux-tower operation. Tower data form a time series relying on mean wind to advect the turbulence past the sensors, while an aircraft, because of its speed, experiences turbulence more as a space series. While on towers the Taylor hypothesis of 'frozen turbulence' has to be invoked to use the time averages as ensemble averages for eddy correlation computations (Kaimal and Finnigan, 1994), aircraft can really measure turbulence in space within very short amount of times. These measurements provide an almost 'instantaneous' picture of the turbulence field over an area and are not affected by temporal trends and non-stationary effects like those experienced by towers. On the other hand, spatial homogeneity over large areas is a crucial requirement for successful aircraft flux measurements. Despite initial successes (Oechel et al., 1998) and continuing technological improvements, such a novel technique still requires large scale validation to better understand its reliability in regional flux estimates (Oechel et al., 1998; Doran et al. 1992; Crawford et al, 1996, Desjardins et al., 1995, Desjardins et al., 1997). The occurrence of substantial differences in the fluxes of scalars measured by airborne and ground based eddy correlation have been observed and discussed at several occasions in the past (Desjardins et al. 1989; Kelly et al. 1992; Desjardins et al. 1992; Crawford et al. 1996). The Sky Arrow ERA is a new platform that has been recently developed in the frame of an international collaboration. This aircraft has been used in the European Research Project RECAB (Regional Assessment and Modelling of the Carbon Balance in Europe) to measure surface fluxes at the regional scale in selected regions of Europe. To assess the accuracy and the reliability of those measurements, an extensive comparison between airborne fluxes and observations made on the ground by conventional eddy covariance towers has been made (Gioli et al., 2004).

The Sky Arrow 650 ERA (Environmental Research Aircraft), a commercially produced, certified small aircraft equipped with sensors to measure three dimensional wind and turbulence together with gas concentrations and other atmospheric parameters at high frequency. It is a two seat aircraft made of carbon fibre and epoxy resin, powered by 100 HP engine. It has a wingspan of 9.6 m, a length of 8.2 m, a wing area of 13.1 m^2, and a maximum takeoff mass of 648.6 kg. The aircraft has a cruise flight speed of 85 knots with an endurance of 3.5 h, allowing it to cover flight distances of up to 500 km. Operating altitudes can range from 10 m above ground level to more than 3500 m above sea level. The aircraft was re-engineered in 1999 to host the Mobile Flux Platform (MFP), which consists of a set of sensors for atmospheric measurements. The installation was certified to operate under both FAA (Federal Aviation Administration, USA) and JAR (Joint Aviation Regulations) aeronautical regulations. Atmospheric turbulence measurements are made with the "Best Aircraft Turbulence" (BAT) probe, developed by NOAA-ATDD and ARA Australia.

In brief, the BAT probe measures the velocity of air with respect to aircraft using a hemispheric 9-hole pressure sphere that records static and dynamic pressures by means of four differential pressure transducers (Crawford and Dobosy, 1992). The Sky Arrow engine is mounted in a pusher configuration, allowing the BAT probe to be installed directly on the aircraft's nose, thus minimizing airflow contamination due to up wash and side wash generated by the wing (Crawford et al. 1996). The actual wind components (horizontal U, V and vertical W) relative to the ground are calculated introducing corrections for three-dimensional velocity, pitch, roll and heading of the aircraft. Those corrections are made using a combination of GPS velocity measurements and data from two sets of three orthogonal accelerometers mounted at the center of gravity of the aircraft and in the centre of the hemisphere. Aircraft velocity relative to the ground is measured by means of a conventional differential GPS (RT20, Novatel USA) at 10 Hz. An additional 4-antenna GPS system (Tans Vector, Trimble USA) is used to measure aircraft attitude angles at frequencies up to 10Hz. Finally, the GPS and accelerometer signals are blended to obtain attitude and velocity data at frequencies up to 50 Hz. Accordingly, atmospheric turbulence is actually measured at a frequency of 50 Hz and since the aircraft can fly at relatively slow speed (35 ms^{-1}), a horizontal spacing of 0.7 m between 50 Hz measurements in no-wind conditions can be achieved. In this way, eddies of wavelengths larger than 1.4 m can be detected. The probe is equipped with a fast response thermocouple to measure air temperature with a response time of 0.02 s. A platinum resistance thermometer is used for a mean air temperature reference. A net radiometer (Q*7, REBS USA) and upward and downward looking PAR radiometers (200s, LiCor USA) are mounted on the aircraft's horizontal stabilizer. Low frequency air moisture measurements are made using a chilled mirror dew point sensor (EdgeTech, USA). Surface temperature is measured using an infrared thermometer (4000.4GH, Everest USA). Atmospheric densities of carbon dioxide and water vapour are sampled and recorded at 50 Hz by a LiCor 7500 (LiCor, Lincoln, Nebraska) open path infrared gas analyzer installed on the aircraft nose. All the digitally converted signals from the BAT Probe and the sensors are stored on a PC located on-board. Additional details of underlying theory and the technical implementation of flux aircrafts can be found in Crawford and Dobosy (1992) and Crawford and Hacker (2001), Dumas et al. (2001). The flux calculation procedure requires the wind components to be derived from the 50 Hz raw data out of the MFP. The subsequent calculation of carbon dioxide, water vapour, sensible and latent heat and momentum fluxes are made using conventional eddy correlation technique taking into account all the necessary corrections for open-path gas analyzers (Webb et al., 1980). The complete computation procedure is written in MatLab v6.0 (Mathworks, USA).

7.2) Regional NEE upscaling procedure

An original method was developed, within CARBIUS, to obtain reliable estimates of regional NEE using a combination of data obtained from the flux aircraft, ground-based eddy covariance towers, weather data and digital land use maps. Aircraft measurements of carbon flux, friction velocity (u*), sensible and latent heat fluxes are made at different times of the day and at several occasions during the year and the flight paths are selected in order to encompass all the major ecosystem types of a study region. The concept is that within each segment of the flight, the aircraft footprint extends over an area of land which is representative of the entire study region. This section describes the methodology used to estimate half hourly values of NEE for the region. Land use classes from digital maps are, at first grouped into main categories like, for instance, deciduous forests, evergreen forests, agricultural land and grasslands. Then the footprint of each individual flux measurement made by the aircraft calculated using a model is overlapped to the re-classified land use digital map and, finally, each individual NEE measured value is associated to the predominant land use class in the footprint. Saturating light response curves are then fitted to the data associated to the four land use classes using a non-linear fitting procedure:

$$NEE = NEE_{\max} \cdot (1-b) \cdot e^{(PPFD/NEE_{\max})} \qquad (1)$$

where NEE is expressed in μmol m^{-2} s^{-1}, NEE_{max} is the maximum value of NEE at saturating PPFD (Photosynthetic Photon Flux Density, mmol m^{-2} s^{-1}) and b is the initial slope of the curve. PPFD values used for curve fitting were average values directly measured by on board of the aircraft during the time of flux measurement. Curve fitting can be made in two steps by separating observations made during sunny and cloudy days. In this way, two curves can be obtained for each land use class to account for differential light response of net ecosystem exchange to diffuse and direct irradiance (Gu et al., 2002). Hourly PPFD data from the ground weather stations are then used to extrapolate NEE values to each hour of the study period, by separating cloudy or clear sky conditions. Fitted light response curves are then used for periods in which measured PPFD values are equal or greater than the minimum value recorded during the experimental flights. In this way, hourly NEE values can be obtained for each land use class.

There are several sources of uncertainty in the methodology described above. Uncertainty is associated to both ground-based and airborne eddy covariance, to the relatively variability in the flux data that are obtained from an aircraft flying over land uses that are not a homogeneous even if they belong to the same class (i.e. agricultural land, or forest patches) and to the variable contribution to the flux of non-homogeneous land use patches that are inevitably associated to a given land use class. In our study, we only consider, for uncertainty analysis, error propagation caused by the variability of the measured data on the standard deviation of the regression coefficients of Equation 1. Confidence levels of the fitted equations are used to estimate a lower and a higher value of NEE for every half-hour of the study period and for every land use class. Regional NEE data are presented, as half-hourly means with an associated uncertainty estimate.

This procedure has been already successfully used, to estimate NEE in an experiment made in The Netherlands, in 2002 (Miglietta et al., submitted). The Dutch territory that was considered in that study is largely dominated by grasslands and agricultural land with a smaller proportion of afforested land (both evergreen and deciduous forests). The percentage of flux data measured by aircraft over each land use class and the percentage of pixels for each class in the land cover classification were comparable thus supporting the assumption that surface flux data obtained by airborne eddy covariance were a good sample of the regional fluxes. The weather conditions during the study period were very well comparable with climatic averages. Mean air temperature, total rainfall and sunshine durations measured from 9 to 31 July 2002 and over the 1941-2004 period allow to conclude that the 20-days period of this study was representative of typical climate for the area. Net Ecosystem Carbon Exchange measured by the flux aircraft correlated, for each individual land use class, to the airborne measured PPFD values. For the forest, NEE values measured at the same PPFD were larger during cloudy than clear sky days. The correlation between PPFD and NEE was the highest for forest than for grassland and arable land use. In fact, while forests that were considered for this experiment were rather homogeneous, grassland and arable land use consisted of a mosaic of different surfaces that included different crops and bare soils as well as different types of grasslands. Not surprisingly, the greater variability in the surface properties and fluxes of those two land use types caused a much greater scatter in the relationship between NEE and PAR. NEE_{max} was higher (more negative) for the forests than for the other classes while the ecosystem light compensation point of NEE (the PPFD value at which NEE is equal to zero) was smaller. The overall significant dependence of NEE to irradiance for all the land use classes undoubtedly indicated that Carbon exchange between the land surface and the atmosphere was mainly driven by photosynthesis during light hours.

A direct comparison of NEE estimates obtained with a combination of aircraft and tower data was only meaningful for the evergreen forest and grassland land uses (Figure 1). NEE data that were obtained for the arable land use class, could not in fact be compared with those of the tower installed over a maize crop as arable land is in fact made by a mosaic of land uses that include different crops, rotations and bare soils and airborne flux data certainly depends on such variability. The validity of the comparison made for the forest and the grasslands has, also, a limited value as aircraft flux data obtained for those two classes originated from widely different situations that could include, over the space encompassed by the experimental flights, different management practices (fertilization, grazing, species) for grasslands and different species and age for the forests. Nevertheless, the data shown in Figure 1 indicates some consistency between the two data sets. Far from being a reliable and solid validation of the aircraft derived regional fluxes, observed similarities between tower and aircraft data indicate an overall reliability of the procedure used for regional NEE estimation. Examples of half-hourly NEE maps calculated for the entire study region are shown in Figure 2. These show the distribution of Carbon sources and sinks over the area at noon on July 22nd, that was a sunny day.

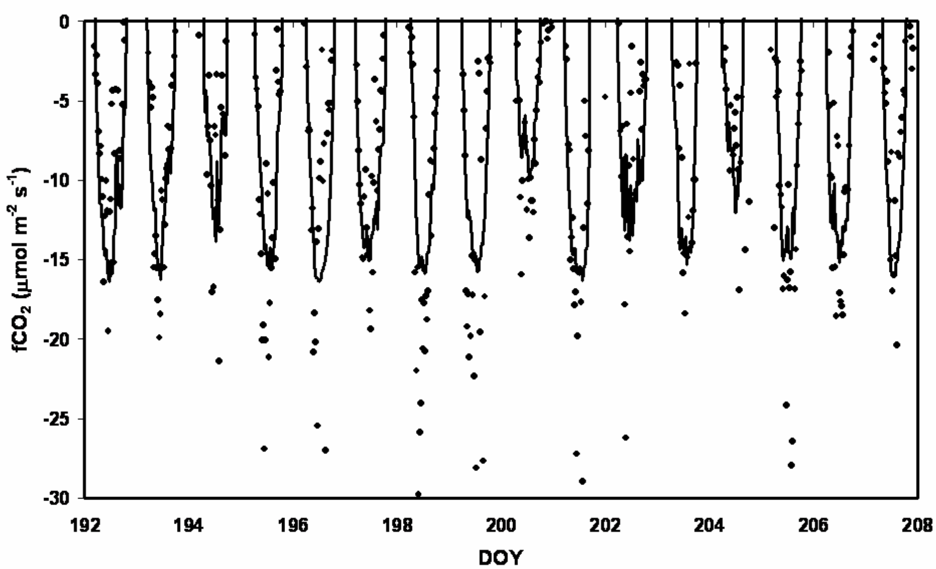

Figure 1: A comparison of daytime NEE estimates made by the eddy covariance tower of the Loobos forest, in The Netherlands (dots) and NEE estimates made by the Sky Arrow ERA (solid line) and that are based on the methodology described in the text. DOY= day of the year.

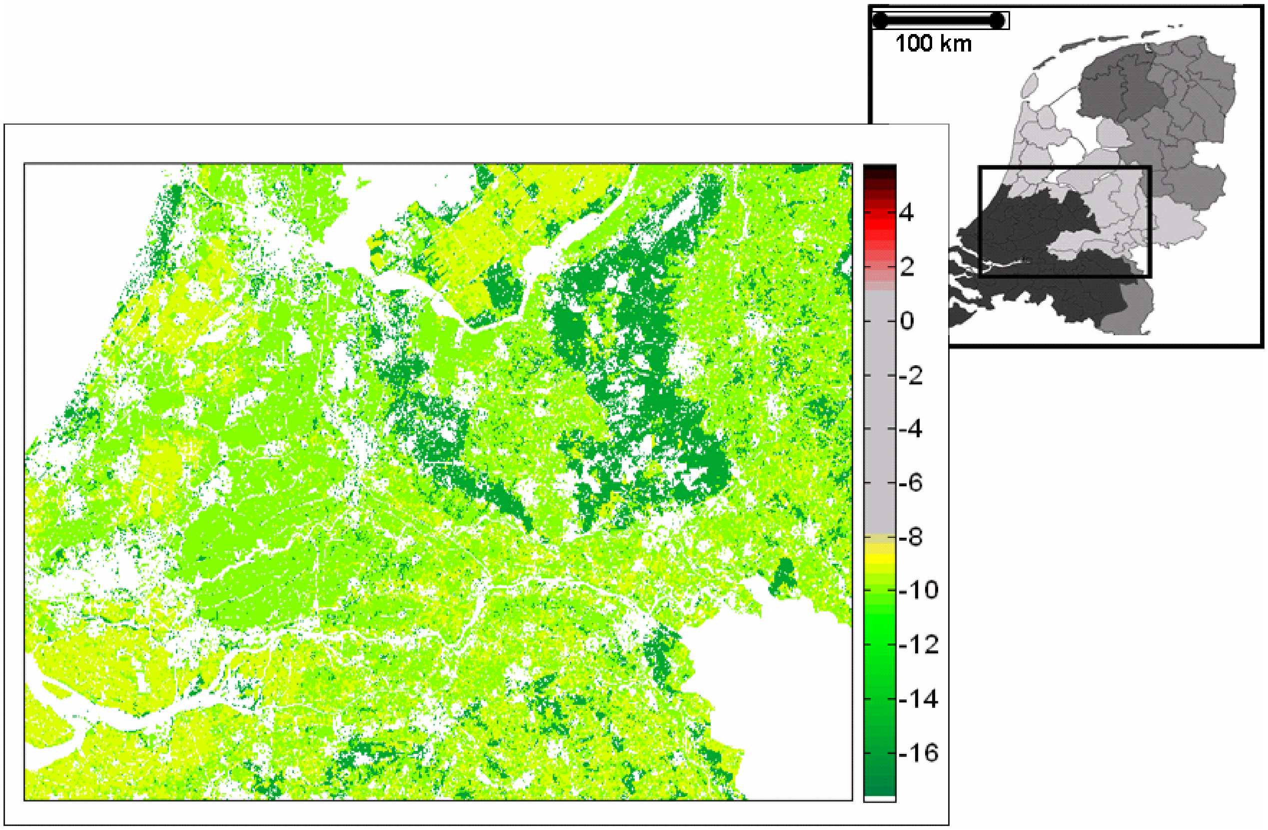

Figure 2: An example of half hourly regional NEE (mmol C m^{-2} s^{-1}) obtained for the central-southern part of The Netherlands on 21 July 2002 at noon. The exact location of the study area is indicated over the geographical map of The Netherlands. NEE fluxes (legend is given by the color coded bar shown in the figure. Forest areas are easy detectable in the figure as estimated NEE are more negative than for other land uses.

7.3) CarbIUS experimental strategy

The approach adopted within CarbIUS, was to select at first a region of approximately 15,000 km^2, in the central-western part of the country (Figure 3). This area includes one of the largest forest areas of Italy (Colline Metallifere, Tuscany) which is covered, for the largest part, by a Mediterranean forest dominated by *Quercus pubescens* and *Quercus ilex* trees. Airborne campaigns have started in the summer 2004 and are still on-going. Campaigns are repeated at approximately monthly intervals flying over selected transects that include both forest and agricultural land uses. Each campaign lasts three days and allows several repetitions of the flight passes under different irradiance conditions (morning, afternoon, sunny and cloudy days). The data are then used to calculate light response curves of measured NEE using the methodology described above. We expect, in this way, to be able to reconstruct, by using weather data and land use maps, the annual course of NEE for the entire region. Maps that will be finally compared with other types of estimates based on ground measurements and models upscaling procedures.

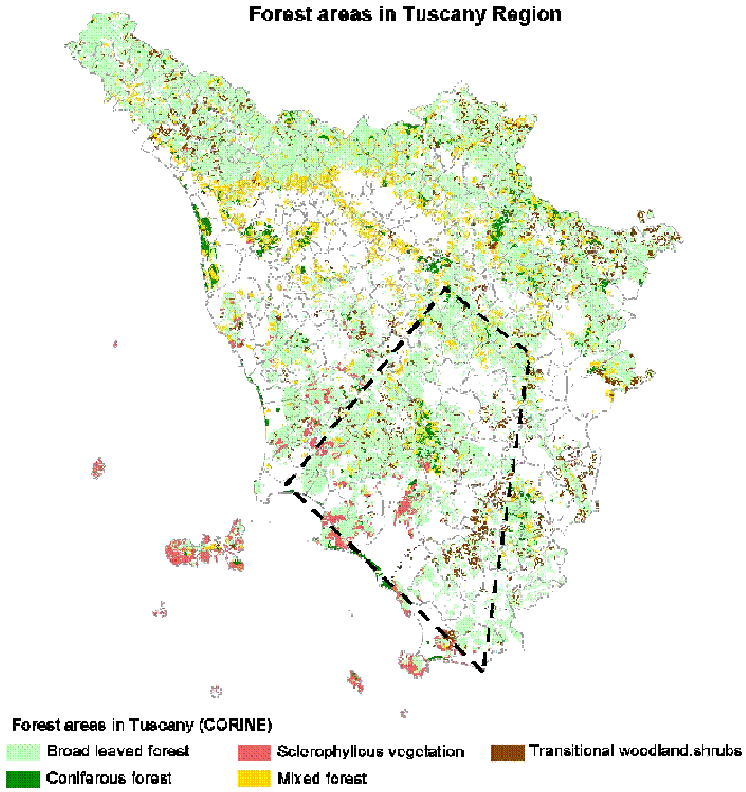

Figure 3: A Corine-based map of forest land in the Tuscany Region (Central Italy). Legend is given in the figure. The study area selected for CARBIUS validation experiment is indicated by the dotted line.

7.4) Acknowledgment: Paolo Amico pilot of the Sky Arrow , Edward J. Dumas NOAA-ATDD, Oak Ridge, TN for the implementation of the flux aircraft

8) First preliminary results

In the next plots and tables are summarized the first results coming from the different component. Although these data are only preliminary and not all the component are assessed yet, we think that it could be interesting to analyze at least the magnitude and role of the assessed component in the definition of the full Italian carbon budget.

In Figure 1 are shown the different assessment of Gross Primary Production and Ecosystem Respiration using three different models based on three different approaches: LPJ (Process Oriented Model), MOD17+ (Hybrid Model) and Artificial Neural Networks (Data Oriented Approach). The results are quite different in particular between LPJ and the other two methods. The NEE obtained (175 Mt $CO2$ yr^{-1}) have to be considered a very preliminary assess and a new more accurate assessment is currently ongoing and will be ready before the end of the project.

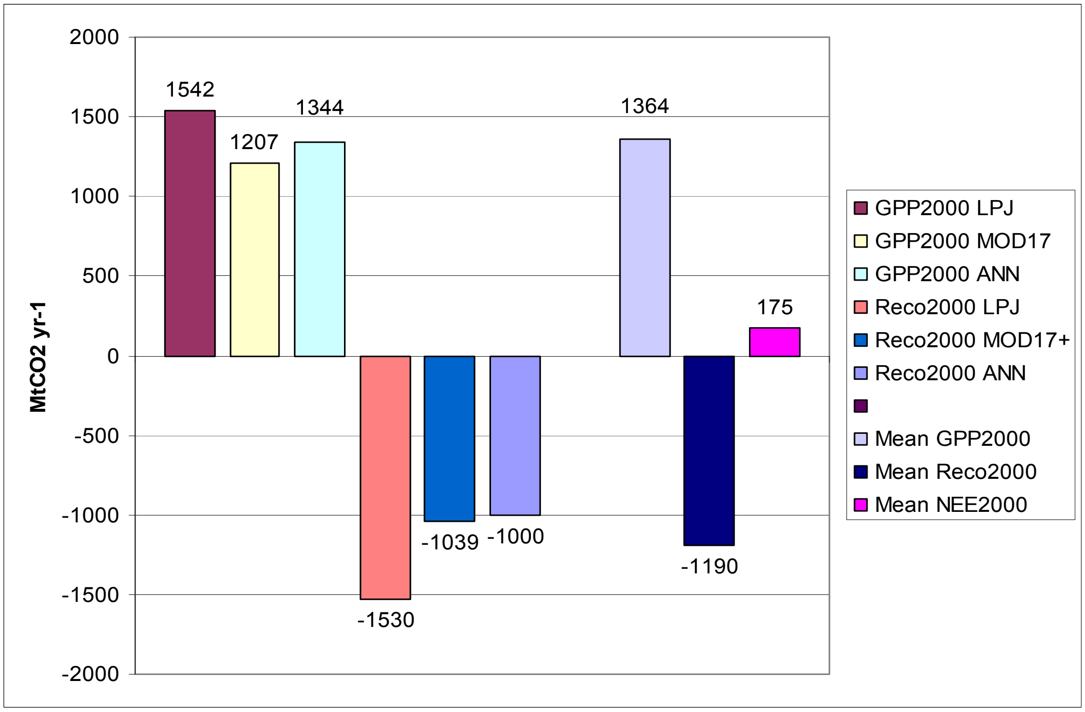

Figure 1: GPP and Reco of Italy assessed using different models: LPJ, MOD17+ and Artificial Neural Networks. Starting from the mean GPP and Reco we obtained a Net Ecosystem Exchange of 175 Mt CO_2 adsorbed by the terrestrial ecosystems in the year 2000. NB: THESE DATA ARE ONLY A FIRST PRELIMINARY RESULT THAT HAS TO BE IMPROVED AND VALIDATED.

Starting from this first assessment of the Italian NEE we tried to compare the magnitude of this component with the others as shown in Figure 2. It is clear that the uncertainties of each component is very high and so that the plot could be change a lot with the final results. It is also important to remember that the NEE assessed using the models described in precedence is the total Net Ecosystem Exchange of the terrestrial ecosystems, included crops and grassland. An assessment of the forest NEE with an independent method was done using difference in the aboveground, belowground and deadwood biomasses in 1990 and 2000 using the data from the National Report to FAO FRA2005. The result obtained is a NEE of about 66Mt CO_2 yr^{-1}, considering the soil in equilibrium.

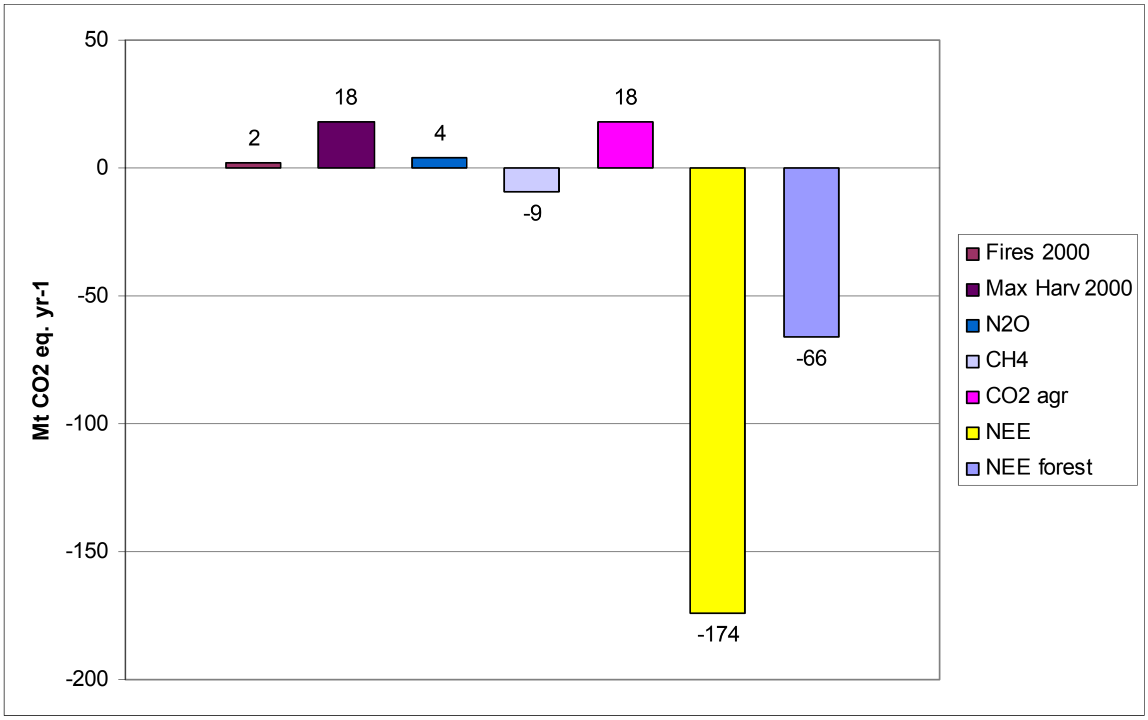

Figure 2: Contribution of the different component in the full carbon budget account of Italy. *Fires 2000*: wild fires in forest, *Max Harv 2000*: maximum contribution possible due to forest harvesting (it is calculated as if the total biomass harvested will be burned or consumed in CO_2 in one year. This is a very conservative approach because the average life cycle of wood forest products can not be easily predicted), *N2O*: N_2O emissions from agroecosystems, *CH4*: CH_4 uptake from natural ecosystems, *CO2 agr*: CO_2 emission from agricultural soils and forests, *NEE*: Net Ecosystem Exchange, *NEE forest*: Net Ecosystem Exchange of forests based on differences of aboveground, belowground and deadwood biomasses in 1990 and 2000 (data from the National Report to FAO FRA2005). In this plot negative values are sinks of carbon. NB: THESE DATA ARE ONLY A FIRST PRELIMINARY RESULT THAT HAS TO BE IMPROVED AND VALIDATED.

Another interesting analysis is the comparison between related to different years and in particular between the 1990, baseline for the Kyoto protocol, and others years. In figure 3 is shown an example of this comparison regarding three types of emission in the Piemonte region in the years 1990 and 2000: forest harvesting, wild forest fires and CO_2 emission from agriculture. The reduction of the three emissions can be due to different climate conditions (fires and respiration), different agricultural practices and forest management. However it is also important to note that for other regions (results not shown) the trend seems to be opposite.

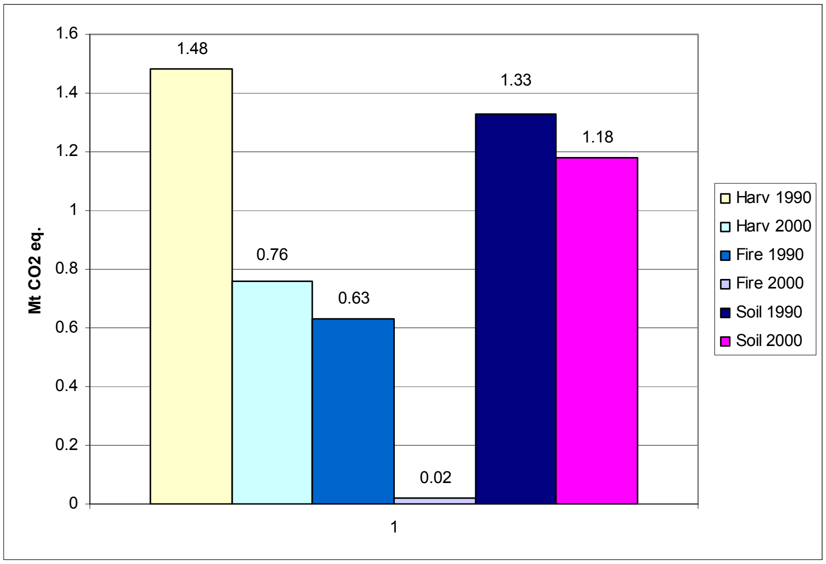

Figure 3: Comparison of the contribution to the carbon budget (Piemonte region) due to forest harvesting (Harv 1990 and Harv 2000), wild forest fires (Fires 1990 and Fires 2000) and CO2 emission from agricultural soils (Soil 1990 and Soil 2000) in two different years 1990 (baseline for Kyoto) and 2000. NB: THESE DATA ARE ONLY A FIRST PRELIMINARY RESULT THAT HAS TO BE IMPROVED AND VALIDATED.

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