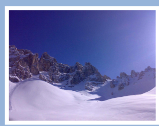
# CLIMATE CHANGE AND AGRICULTURE

*Climate change could have major effects on the agricultural production. A recognition of the main issues of this topic is reported in this essay, including an example of effects on grapevine.*

## 1. The issue of climate change: not all changes are equal

By definition, climate is the atmospheric state in its typical features at one site. The notion of climate itself, in this broad meaning, is not limited to its average values, nor does it imply its stationariness: also variability has a role in the definition of the climate. Having ascertained that climate changes have always occurred in the history of Earth, the extent of a change has to be assessed and studied by considering two main factors: its time scale, and its origin. Considering the whole lifetime of Earth, major changes have taken place, which brought on dramatic changes in the environmental conditions, so that nowadays we know that the same geographic regions experienced, in different geological eras, both wet and arid conditions, and both cold and warm periods, with biomes changing from luxuriant to desert.

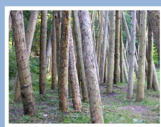
***Key-features***



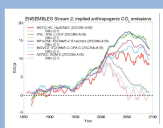
The present climate change is a planetary phenomenon, but some areas – Alps are among these - have undergone a higher temperature increase.

Major effects on the agricultural production are expected mainly due to possible water shortage in summer.

Agriculture adaptation to changes envisages shifting in timing, and also in variety or even crop choice. Not all agricultural setups in the world show enough resilience to manage this change.



Even if the general focus must remain on the possible insufficient growth in food production, other issues include changes in plant/pathogen interactions, or changes in quality. Results cannot be generalized, but have to be referred to any particular case (region, type of crop, etc.)



ENVIROCHANGE has built a complex data processing chain to downscale large-scale climate models to local climate measurements. A multi-model ("ensembles") approach was used, that allows a probabilistic assessment of the climatic signal expected for the future. Results have been detailed down to daily and even hourly time series, useful for an eventual application of biological modelling.

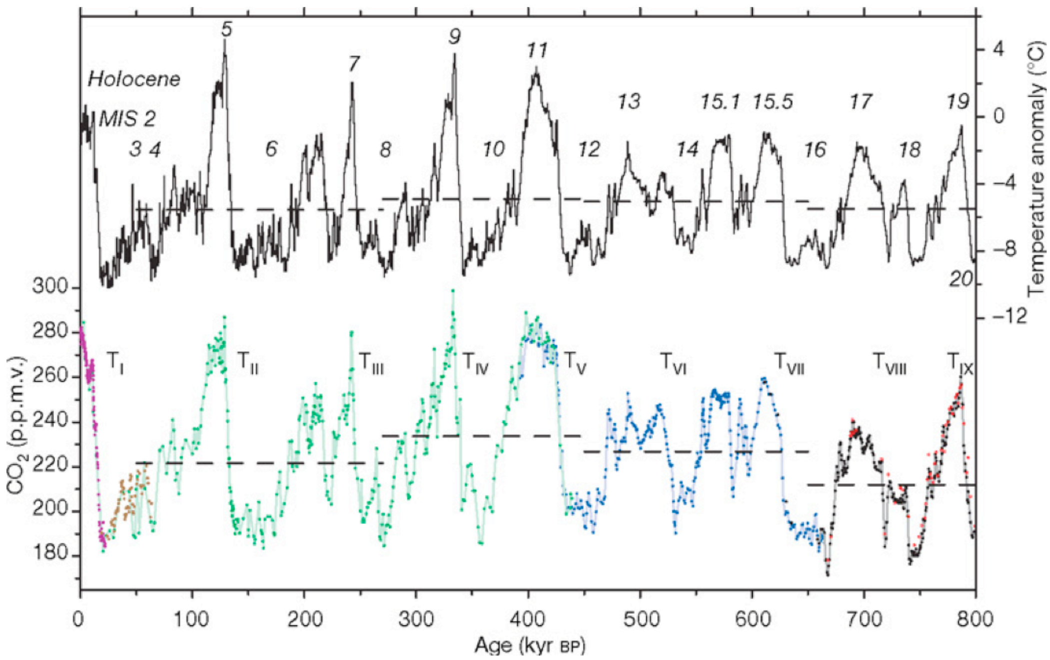



Fig. 1 - Temperature and $CO_2$ anomalies during the last 800 000 years (from Luethi et al., 2008).

If we look back before the last ice age (fig. 1), it is clear that there were warmer periods than the present, particularly the latest interglacial period (Eemian, 110 000 – 130 000 years b.p.). As well, ice periods were generally longer, with considerably lower temperatures than in the present time.

But since the end of the latest ice age, that is during the Holocene period, Earth experienced a relatively stable climate period, and the very recent change has to be considered in this contest. Even during this "homogeneous" period, some important changes took place: particularly important for Europe, and its history, are the so-called "Medieval Warm Period" (or Medieval [Climate] Optimum"), 9th/10th to 13th Cent., and the "Little Ice Age", mid 16th to mid 19th Cent.

But in the "Anthropocene" era, none of these periods showed the characteristics of the present warming, matchless in both extent and speed with which the phenomenon has

Both the periods remarkably affected the setup of rural society, for example by allowing tillage of previously unfit mountain areas, or by getting more and more difficult to maintain those advanced settlements that had been laboriously gained some centuries before, or by hampering more and more the growing of certain crops under new conditions.

***Anthropocene***

*This word was popularized by the Nobel Prize Paul Crutzen in 2000. It stands for the most recent period of the history of Earth, during which human activities have had a major impact on the Earth's climate and ecosystems.*

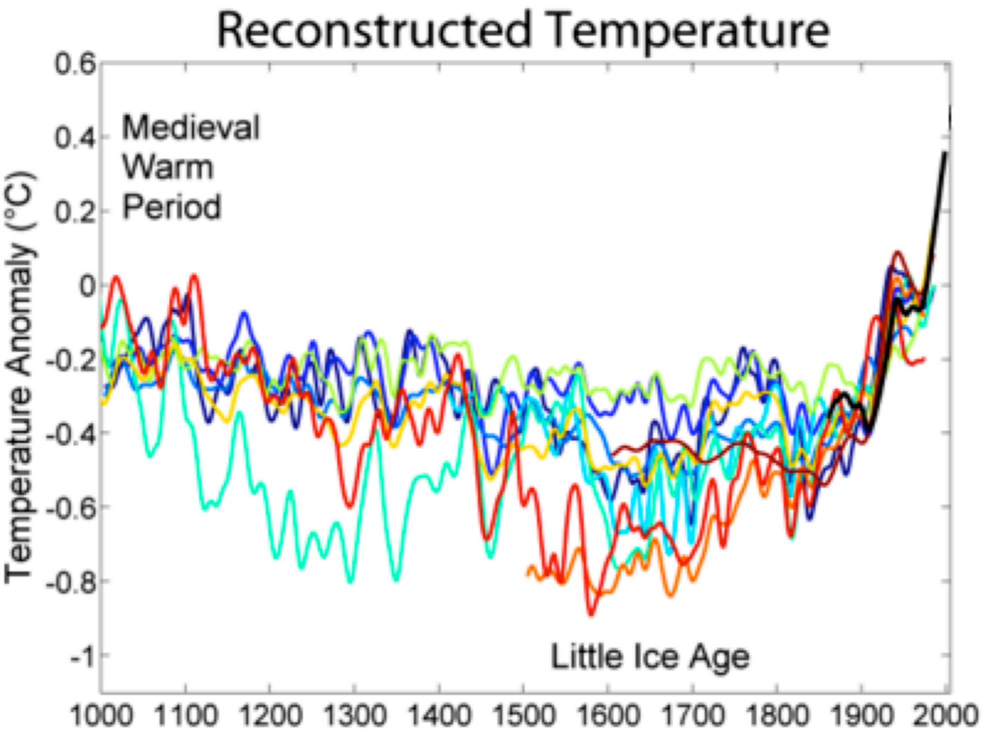



Fig. 2 – Reconstructed Earth temperatures from several sources. From R. Rohde (http://www.globalwarmingart.com/)

Fig. 2 shows several reconstruction curves for the global temperature of the last 1000 years. As it can be seen, reconstructions do differ one another, because paleoclimatology must rely upon "proxy data", that is, measurements of the traces that temperature left on physical or biological media, as tree rings, lake and marine sediments, speleothemes, and ice cores. Each of these methods offers a particular aspect of the climate reconstruction, different from the other approaches, given its specificity, often linked to the seasonality of the phenomenon that is detected (e.g.: tree growth can be tracked in summer for some species, in spring for some other species…), but also considering the sparseness of data. At present, the sample that allows the longest temperature and $CO_2$ data series is the ice core drilled in Antarctica "Epica Dome C": the temperature and $CO_2$ series is 800.000 years long.

***Epica Dome C***

*EPICA stands for* European Project for Ice Coring in Antarctica.
*Dome C is an area situated on the top of the Antarctica Plateau. It is the largest desert on Earth. In summer, temperatures barely reach -25°C and can drop below -80°C in winter. Humidity is low and it is also very dry, with very little precipitation throughout the year.*

## 3. An unprecedented change

The global average surface temperature has risen approximately by 0.74 ° C in the last 100 years, but warming was faster in the most recent decades. Europe has warmed more than the global average, with an increase of about 1°C since 1900, mostly attained in the last 50 years. Nevertheless, it has been often claimed that the last 10-15 years have not continued the paramount increase of the previous decades, or even that no temperature trend can be detected in this recent period. Indeed, it is a methodological fault to seek trends over too short periods, because climate short-term variability may conceal the true long-term trend, and also because single anomalous years (like 1998) do impact on short trends calculated for the close following period (fig. 3).

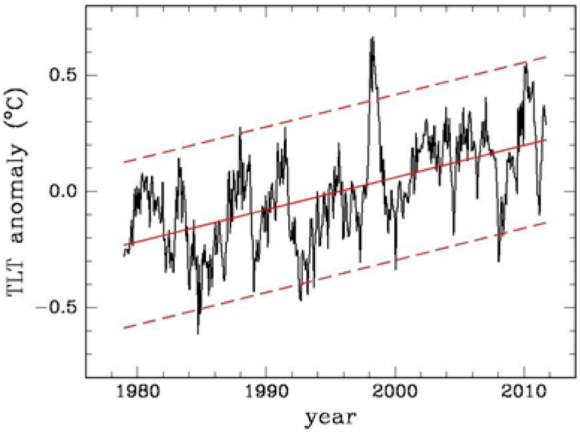



Fig. 3 - Planetary temperature anomaly (difference from the mean) series with 95% confidence interval. From R. Reitano (http://www.climalteranti.it/)

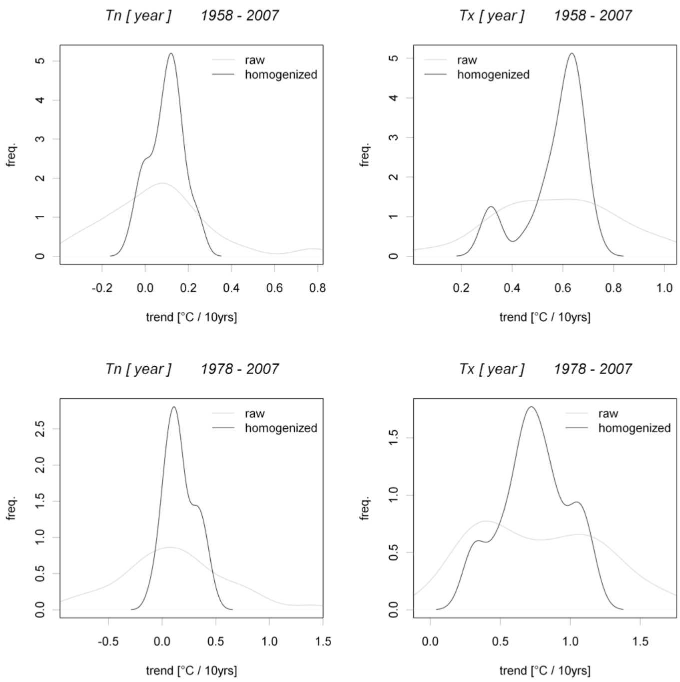



Fig. 4 - 50-year temperature trend distribution calculated over 43 climate series in Trentino. Tn = minimum temperature, Tx = maximum temperature. From Eccel et al., 2012.

There can be found evidence of continuous occurrence of intense meteorological events in the last 10 years, which can be attributed to the human influence on climate (e.g. Comou and Rahmstorf, 2012).

In the Alps, and particularly in Trentino, where we have analyzed data for the last 50 years, there has been a very high increase of temperatures, even stronger in the last 30 years. However, the increase is different from one site to another. Fig. 4 shows how temperature trends in the last 5 decades are scattered in Trentino, and also the highest increase in maxima than in minima.

It is evident the increase of temperature-derived indices that are relevant for agriculture, as the growing season length (on average: 10 days longer than the average 1961-’90), and of the warm spell durations, as well as of the extreme summer temperatures.

On another side, no really important changes in precipitation amounts have occurred in the same period (Di Piazza and Eccel, 2012).

## 4. The anthropogenic climate-change drivers and the role of agriculture

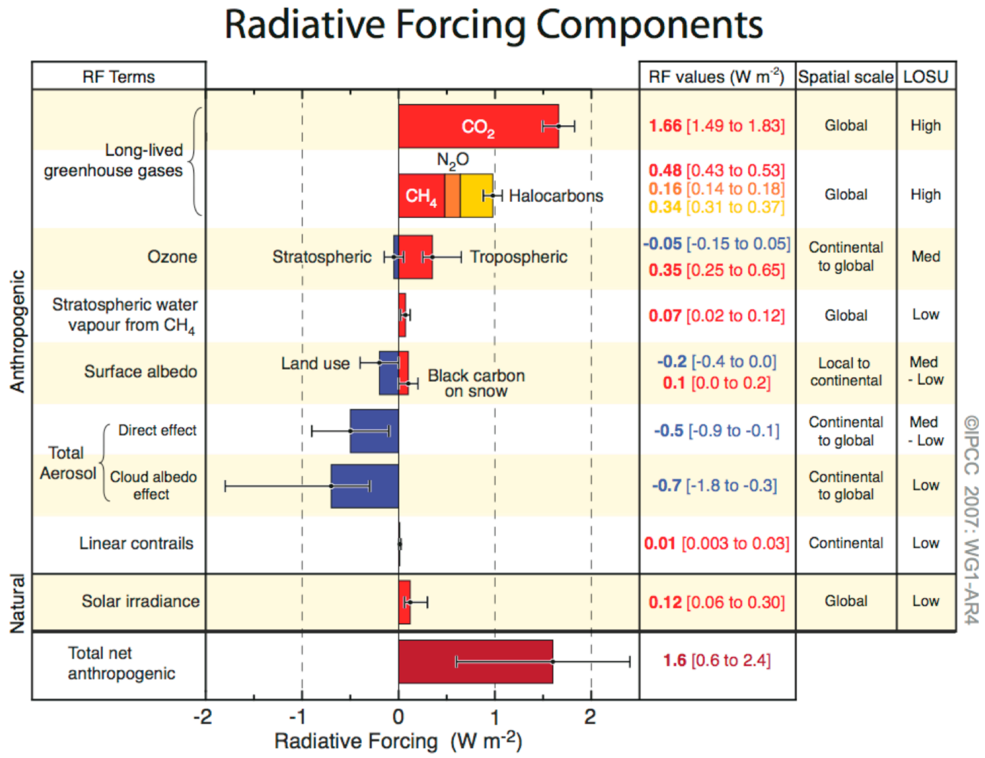
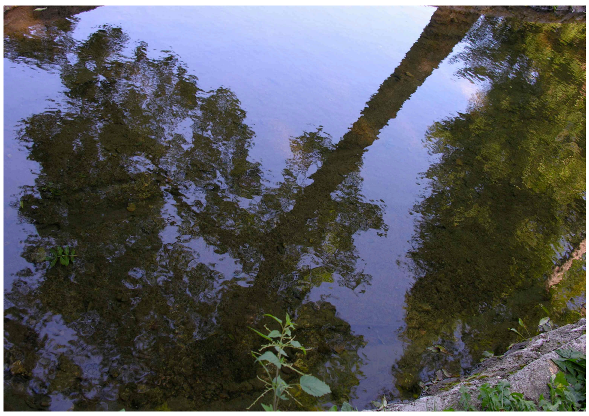



Fig. 5 - Global-average radiative forcing (RF) estimates and ranges in 2005 for anthropogenic greenhouse gases and other important agents and mechanisms, together with the typical geographical extent (spatial scale) of the forcing and the assessed level of scientific understanding (LOSU) (from Solomon et al., 2007).

Global emissions of $CO_2$ – the most important "greenhouse gas" (GHG) - increased by 45% between 1990 and 2010. There is much science between atmospheric composition and climate, and there is a general assent that human activities have a direct effect on Earth's temperature, even if the "sensitivity" of the system (the rate of temperature increase arising from a doubling of the $CO_2$-equivalent content in the atmosphere) is still a debated question. Also the assessment of the human responsibility in the present temperature increase from what is considered a baseline (the pre-industrial era) is not fully understood yet.



***Agricultural and Forest Meteorology***

*To deepen the topic of the contribution of agriculture to the state of climate:*
Agricultural and Forest Meteorology
*(Desjardins et al., 2007).*

## 5. Impacts of changes on crops: the core issue

Climate projections for Europe show increases in temperature and different patterns of precipitation with widespread increases in northern Europe and decreases over parts of southern and eastern Europe. In many countries and in recent years there is a tendency towards increased yield variability. Olesen et al. (2012) report the results of a European-wide survey based on the responses to questionnaires on perceived risks and foreseen impacts of climate and climate change on agriculture. The results show that farmers across Europe are currently adapting to climate change, in particular in terms of changing timing of cultivation, as a response to the general phenological advance, and selecting other crop species and cultivars. The responses in the questionnaires show a surprisingly high proportion of negative expectations concerning the impacts of climate change on crop production throughout Europe, even in the cool, temperate northern European countries. Indeed, surprisingly enough, the expected impacts, both positive and negative, are just as large in northern Europe as in the Mediterranean countries. So, what are the true concerns of a climate change for agriculture? From the abovementioned survey, it turns out that worries are largely linked with the possibilities for effective adaptation to maintain current yields.

Nevertheless, agricultural resilience to climate change is potentially much higher than for natural biomes, if adaptation processes are undertaken, leaving 'potential impacts' a mainly theoretical concept (Reidsma et al., 2009).

Adaptation actions include exploitation of new agricultural areas (where possible), changes in the setup of agricultural areas (Simelton et al., 2009), shifts in the timing of field operations, change of cultivars, or even of crops, optimization of water use.

The latter is, perhaps, the issue that deserves the greater attention for designing future scenarios in southern Europe agriculture. There is a large agreement among climate models in projecting a strong decrease, in the Mediterranean area, of the summer rainfall supply, accompanied by a stronger-than-average temperature rise, as can be seen by multi-model approaches in climate projections (van der Linden and Mitchell, 2009).

The possible increase in water shortage and extreme weather events may cause lower yields, higher yield variability and a reduction in suitable areas for traditional crops (Olesen and Bindi, 2002). In general, the combined effects of "$CO_2$ fertilization" and climate change should increase productivity in Europe (Ewert et al., 2005).

However, in many warm areas of the world, including southern Europe, water scarcity is likely to show detrimental effects that may negatively offset (example in fig. 6) the possible enhancements of productivity of a larger concentration of $CO_2$ in the atmosphere and of a longer growing season, particularly for those crops that have their main developmental cycle in summer (Giannakopoulos et al., 2009).

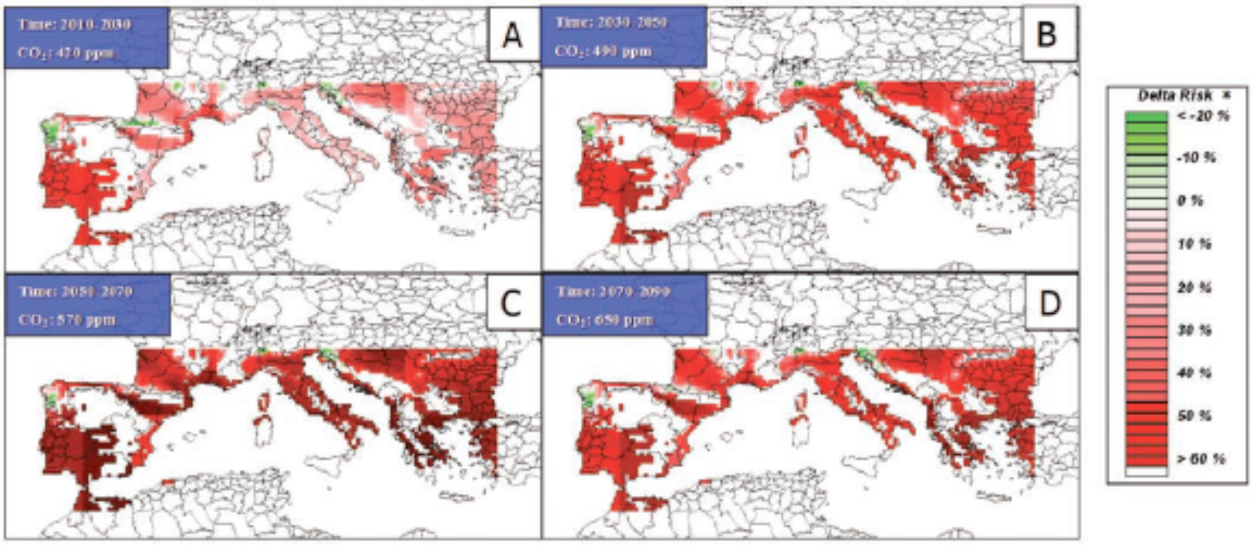



Fig. 6 - Spatial plots of changes in durum wheat risk of yield shortfall by: (a) 2010-2030, (b) 2031-2050, (c) 2051- 2070 and (d) 2071-2090, relative to the baseline (1961-1990). Shortfall is defined as yields below the 20th percentile (one year out of five) yield calculated for the present-day period 1990-2010 (from van der Linden and Mitchell, 2009).

In general, the predominant impacts of change are expected from changes in the precipitation regime, more than from $CO_2$ fertilization and temperature increase (Kang et al., 2009), with different results according to the soil properties, and perhaps even more from the actual possibility of supplying water by irrigation.

Indeed, productivity simulations are often uncertain because they have to cope with a complex interrelation network of drivers as: water use efficiency change, due to the higher rate of evapotranspiration; degradation of soil organic content, due to the higher temperature; effects of (expected) higher climatic variability; and so on. It is not infrequent to find apparently conflicting results in different studies.

The interest in productivity simulation studies is high; a world population of more than 9 billion is estimated by 2050, with most of the increase in developing countries.

In those areas, 80 percent of the necessary additional production is expected to come from increases in yields and cropping intensity and only 20 percent from expansion of arable land. On the other hand, the global growth rate of yields of the major cereal crops has been steadily declining, lowering from 3.2% per year in 1960 to 1.5% in 2000 (FAO, 2009).

### *Productivity simulations*

*A key question in modelling climate change impacts is the prediction of yields. This is the result of the application of mathematical models that simulate the behaviour of crops (mainly cereals) as a function of meteorological trends, either measured or predicted. When used for forecasting crop yields for the ongoing season, they typically couple the measured meteorological series to seasonal weather predictions. When they are used for the prediction of climate change impacts they are applied to the simulated climate series, to assess trends in crop productivity. See, e.g., the JRC's MARS group at Ispra (I) http://mars.jrc.ec.europa.eu/mars.*

## 6. Local-scale impacts on crops: one highlight

Obviously, the food production issues must remain the greatest concern about food production in a globalized society, to maintain a social and economic status-quo.

However, other studies have tackled the impacts of climate change with more particular, site-specific interest. As an example, some of these were aimed at estimating the influence of a progressively warming climate on the quality of some particularly sensitive crop, first of all grapevine. The general feeling, based on observational experience, is that warmer ripening seasons have had, in the past decades, a positive effect on wine quality, at least in temperate-to-cool climate areas (an example is given in fig. 7).

In Bordeaux (varieties *cabernet s.* and *merlot*), for the period 1949-1997, larger berries have been measured, with a better sugar/acid ratio, leading to a higher rating. Interannual variability has generally, positively decreased, too (Jones et al., 2005). In general, these authors found an improvement of the quality of premium wines, statistically correlated to temperature increase during the vegetative season (April to October). However, there are well-grounded suspicions that an indefinite increase in temperature will not lead to ever improving wine ratings. Fig. 8 (by Jones et al., 2005), shows how an optimum temperature value is attained, beyond which no further improvement in rating is to be expected.

On the contrary, other shortcomings may arise, like excessive evapotranspiration rates affecting the field water budget, or even a quality decrease due to too high temperatures. This is particularly true for white grapes and sparkling wines, for which ripening with hot temperatures has a detrimental effect on flavours.

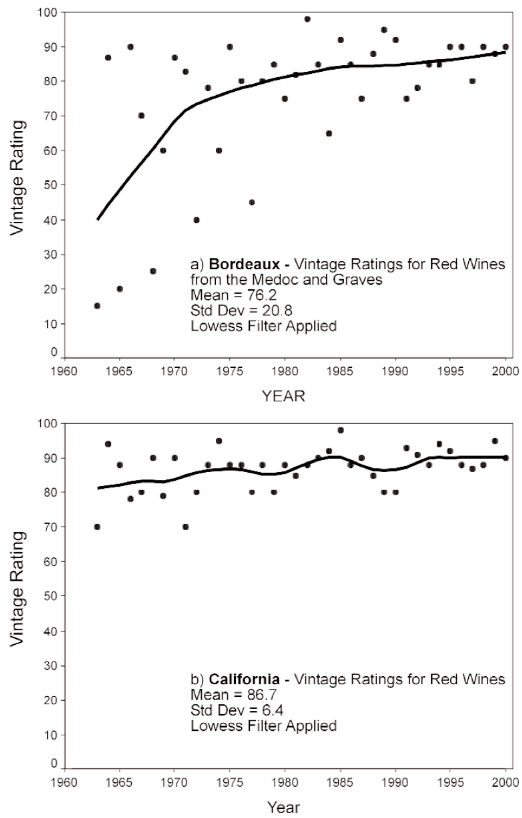



Fig. 7 - Vintage ratings for (a) red wines from the Médoc and Graves regions of Bordeaux and (b) red wines from California as analyzed by Jones (2003). The ratings are from Sotheby's and are based on a 0-100 scale.

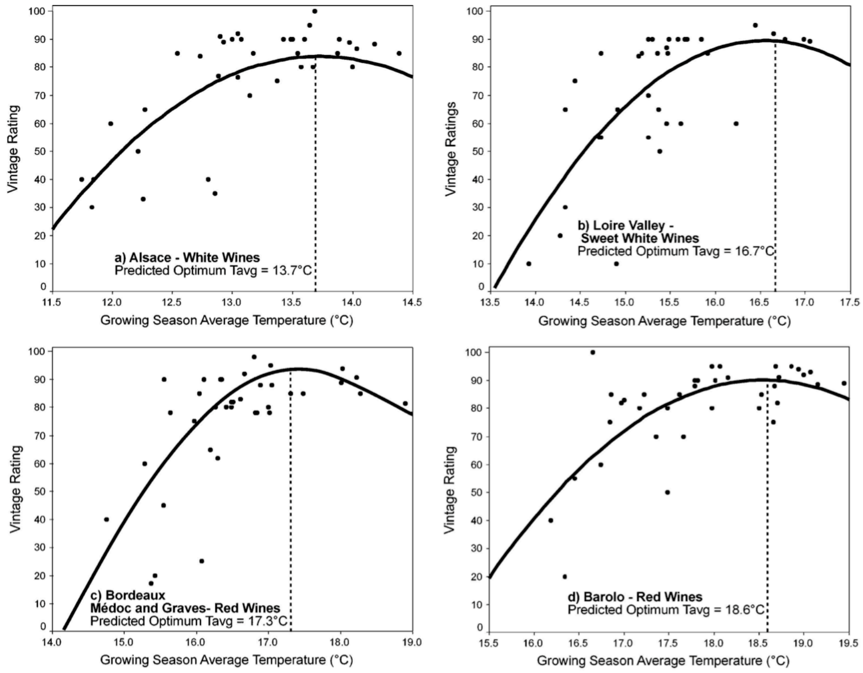



Fig. 8 - Predicted optimum growing season temperatures for a) Alsace white wines, b) the Loire Valley sweet white wines, c) the red wines from the Medoc and Graves of Bordeaux, and d) the red wines of Barolo. The dashed lines represent the quadratic model predicted optimum for each region shown. (from Jones et al., 2005)

Apart from the issue of quality of crops (but directly linked to it), there is also the concern of possible changes in phyitosanitary management of crops: warmer temperature foster a higher developmental rate for parasites, but it speeds crop phenology as well; and different humidity conditions may favour (or hamper) the development of pathogens. Of course, results vary greatly according to the crop and the region of the world where studies are aimed.

### *Crop phenology*

*Plant phenology is the science that studies the occurrence of the vegetative and reproductive stages in plant life cycles. A typical investigation is the creation of mathematical models that simulate the timing of crop annual cycles as a function of the meteorological drivers (mainly temperature).*

## 6. Hints for mitigation of agricultural impact on climate change

The potential of reduction of net emissions of $CO_2$ and $N_2O$ have been estimated at about 8 % of the total GHG emissions in EU 15 (Grünberg et al, 2007). Best practices aiming at this scope include:

- substitution of fossil fuels through biofuel production and anaerobic digestion of manure
- improvement in feed intake and feed digestibility for livestock, while improving productivity, and improved handling and storage of manures; breeding of more "efficient" animals adapted to the local natural conditions
- controlled irrigation and better nutrient management as well as new high-yield varieties for cereal production
- crop rotation as main crop system and use of polyculture
- reduction or rationalization in the use of mineral fertilizers, especially nitrogen
- restoration of cultivated peaty soils and degraded land
- use of more energy-efficient machinery
- no-tillage (or minimum tillage, avoiding autumn tillage and reducing the number of tillage passes); direct sowing through a permanent soil cover of vegetation or crop residues.

These practices increase the level of soil organic matter, thus improving soil structure, and have a high rate of carbon sequestration. By reducing or eliminating tillage, less $CO_2$ is emitted by the exposed organic matter.

The in-situ plant cover is preferred over mulch brought from other sites, because this implies carbon losses in other places. The risks of erosion and desertification would be also reduced.

The combination of crops and trees - agroforest systems - is a very effective system, since the carbon sequestration due to trees can be accounted for.

However, the abovementioned practices are specific to some crops (typically cereals), or to animal production, and will have an easier penetration into a technologically careful agribusiness, since an aware attitude and an up-to-date approach are mandatory prerequisites. Traditional farming will probably remain long unaffected by proposals of change in the usual practices.

***Biofuel production***

*The word "biofuel" designates a fuel whose origin is from "energetic crops", like cereals or other crops whose tissue or seeds are rich in energetic content. Even if, in principle, this energetic source is renewable, its "emission footprint" is not so favourable as it could seem. Energetic crop growing implies its own greenhouse gas emission, as well as water consumption. Since its general spread, a couple of decades ago - also spurred by the rise of oil price - its global sustainability has become a heated argument of debate, particularly when the fuel is derived from food crops, due to its impact on prices. See, e.g. http://www.esa.org/pao/policyStatements/Statements/biofuel.php*

## 7. Climate modelling for ENVIROCHANGE

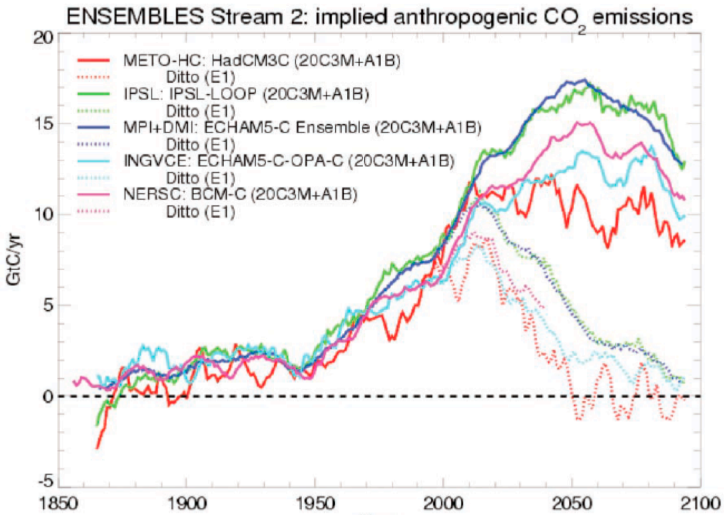



Fig. 9 - Anthropogenic net $CO_2$ emissions to the atmosphere (Gt C/yr) in scenarios A1B and E1, 20th and 21st century (from van der Linden and Mitchell, 2009)

In order to simulate any effect of climate change on the equilibrium of the plant /pathogen-parasite, climate simulations are needed. A number of choices have to be done to drive the model simulations: the atmospheric composition scenario (in turn, a result of the global socio-economic evolution expected – see fig. 9), the choice of the climate model (not all predict the same way- see fig. 10), the statistical processing of its output (what is a typical meteorological year? What is the probability of having an anomalous season?).

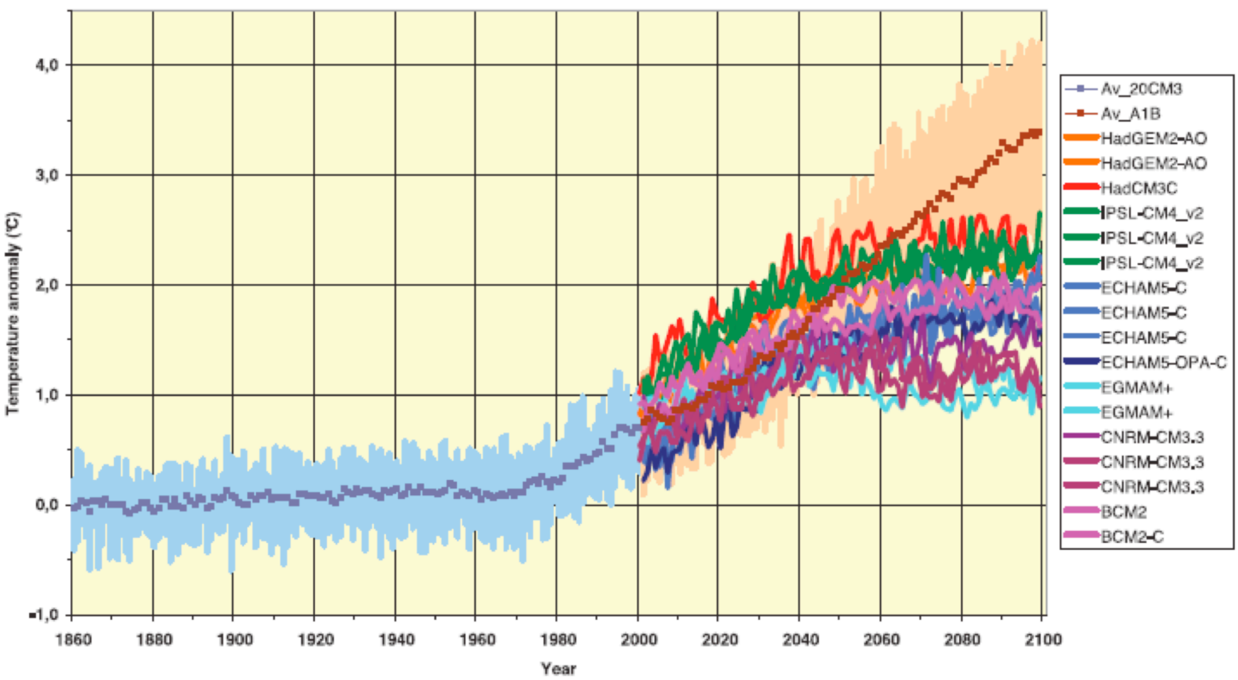



Fig. 10 - Global average temperature projected by a range of models in scenarios A1B and E1 in the 21st century (from van der Linden and Mitchell, 2009).

To cope with these uncertainties, a multi-model approach is probably the best. This was the choice for EnviroChange. The method ("ensembles") makes use of several model outputs and connects the results considering their statistics, for example, by choosing the median value of the output, so avoiding results too far from the mean. The output here is not the direct original model output, but the values downscaled to the sites where simulations are aimed. This fundamental pre-processing relates the large-scale output from Global Circulation Models (GCMs) to the local climate features expressed by the instrumental series available for calibration.

The general protocol for the production of prediction series is shown in Fig. 11.

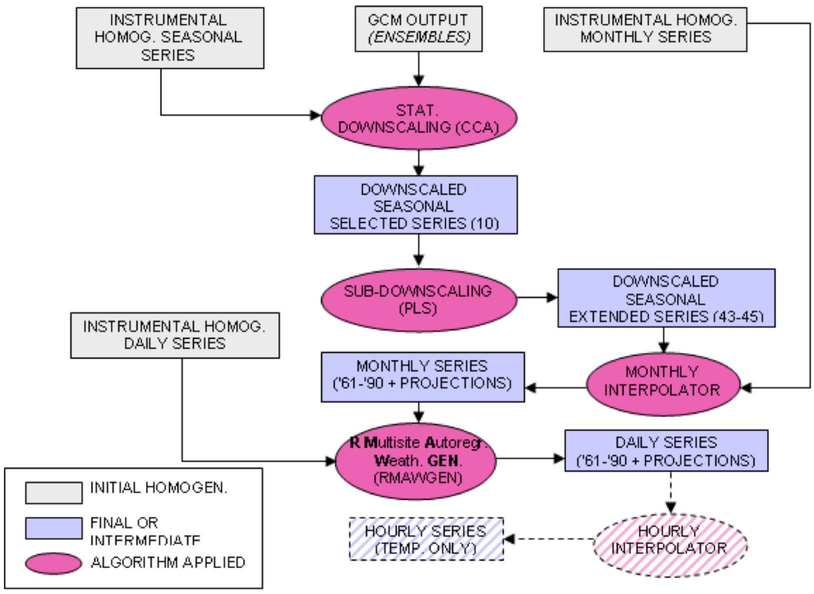



Fig. 11 – The general protocol adopted for climate modelling in the project EnviroChange.

Climatic projections were downscaled for a selected number of high-quality series (10), by a Canonical Correlation Analysis technique (collaboration with ARPA Emilia – Romagna). Outputs from EU Project "Ensembles" were used (7 GCMs, scenario A1B). At this stage, only the model median of outputs was used for each site.

The projection periods were the standard ones of project "Ensembles": 2021-2050 and 2071-2099 (30-year means). A "sub-downscaling" algorithm was used to extend the statistical downscaling, originally carried out on 10 sites, to all the remaining ones by a "partial least square regression" approach (see fig. 12).

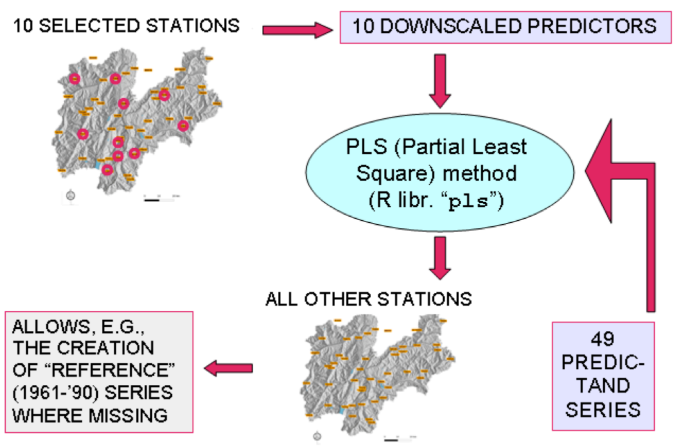



Fig. 12 – The flowchart for "subdownscaling" climate series, both for reference past periods and for future projections.

Monthly values were used as input for a multi-site "weather generator" to produce daily series from seasonal averages and projections. The weather generator allows to generate an indefinite number of stochastic daily series, each one meeting the given climatic features, coming either from the instrumental climatology (like the "reference period" 1961-1990) or from downscaled projections for the future. More details on the weather generator can be found in Cordano and Eccel (2012).

The weather generator yields a number of yearly simulations of daily series, which can be used for further processing, like the phenological or plant/parasite interaction models. From this multi-series output, the simulated natural variability of climate can be reproduced and chosen, for example, by selecting singular seasons (the warmest, the coldest, the average, the 25$^{th}$ percentile), so to reproduce diverse scenarios for eventual model applications.

**To know more**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# THE ENVIROCHANGE PROJECT

The EnviroChange project focuses on global change and sustainable management of agriculture in highly developed mountain environment.
It aims at assessing the short-term biological, environmental and economic impact of climatic change on agriculture at the level of the Trentino region particularly on quality and pest management that are more likely to be influenced by climate change in the short term. The final aim is to preserve and improve the quality of life of habitants, protecting environment and biodiversity for the future generations, as well as to represent a model for sustainable development of mountain areas.

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