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The modification of rural vineyards landscapes: agroclimatic and phenological analysis in relation to possible climate change

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for my parents

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Index

Index of figures

Foreword

A culture of identity can be kept if and only if it preserves the rural landscape within which it was formed over the centuries (Tempesta, 2008). The rural landscape in the past represented a visual synthesis of a series of real human choices that also affect the environment and natural surroundings significantly. The landscape does not end as an aesthetically valuable visible horizon, but it weaves a constant dialogue between economy, culture, traditions, architecture and expressions of nature (Tempesta, 2013; Moretti, 2016).

The Italian viticulture has left, over the centuries, deep identification marks on the rural landscape. It still continues to be an identifying mark of a territory through cultural practices that are intertwined with urban areas, villages, wineries, separate houses, outbuildings, cultures and economic and social activities of the area (Iacono, 1999).

Based on these premises, in relation to the work of the European Union on the European Charter of the landscape and to the concept that the Terroir is the interaction between grapevine, environment and the human factor of growers (Fregoni, 1998), by analysing the weather component and the relationship between the thermal element and the phenological response, I started this type of studies working as an ecologist since 2008 in the Regional Agency for Environmental Protection of Sardinia, (Arpas), and I produced some bioclimatic indices for grapes at a resolution of 250 m in a research project Convisar SQFVS[1], carried out in Sardinia by a consortium of nine wine firms and the University of Sassari.

At that time I was building my phenological experience into the Italian Phenological Network[2] (Mariani *et al.*, 2012), through a long collaboration with Prof. Luigi Mariani and the University of Milan (Mariani *et al.*, 2007). I had just achieved my second degree in Architecture, and I was fascinated by the idea that quality viticulture can improve results not only from production and farm income, but about the quality of the agricultural landscape and its effect. Landscape, in a small and heterogeneous island like Sardinia, rich in differences geographical, geological, climatic, vegetation, historical and cultural, influences the regional vineyard spread of 26,000 hectares.

The first year of the research project coincides with the agroclimatic characterisation, focusing the study on some viticultural areas of northern Sardinia. We were going to support the primary

[1] http://www.sardegnadigitallibrary.it/documenti/17_151_20130327091447.pdf

[2] http://cma.entecra.it/iphen/

role of vineyards in agricultural landscape (Pielke, 1990; Valeriu *et al.*, 2013), along with that of olive trees, by two main actions: to collect data from the most important wine companies; to verify the relationship between phenological data and thermal resources estimated by means of suitable methods applied to meteorological datasets.

Figure 1 - View of Sella and Mosca vineyards

Normal Heat Hours, (NHH), and other bioclimatic indices useful to describe thermal resources for selected vineyard. Here were highlighted the first real problems that affected the work: the quality of agro-meteorological data, the position of agro-meteorological stations, the continuity of the historical data. When we started to work with an improved spatial resolution, from 250 x 250 m to 40 x 40 m, in order to have a better accuracy, we encountered and solved numerous geostatistical problems. A first testbed, in the second year of the Ph.D., had been the work on the Rural Landscape of Sardinia for the Department of Local Finance and Urbanism of the Sardinia Region "The definition of a methodology for the identification and mapping of rural landscapes in the regional ambit and the correct insertion of settlement artefacts in a natural reference. " The research project saw the involvement of the Departments of *Agriculture* and *Nature and Territory*, of the University of Sassari. Also during the second year there had been a collaboration with Sella and Mosca Wines, a vine firm, whose vineyards of about 500 hectares located in the Algherese Nurra, provided us with their long time series field data, which allowed us to analyse thermal data and phenology of local varieties.

The third year of the doctorate was characterised by experiences abroad: the Socrates project allowed me to investigate the history of the phenology during a fifty-day internship in Spring 2016 at Shimane University[3], Matsue, Japan, under the supervision of Prof. Akira Yano and Dr. Marco Cossu., close to the *Adachi Museum*[4], one of the most important Japanese Gardens in the world, winner of the most beautiful garden prize of Japan for many years; it was an opportunity to learn about and study Japanese agricultural systems and many Japanese Ornamental Gardens with interesting reflections on a sustainable rural landscape.

Figure 2 - The *Adachi Museum of art,* Shimane. Main view

I had the opportunity to visit it, and visit in Tokyo the site that hosts the longest phenological series (800 A.D. - now) of Cherry blossom in the world at the *Imperial Palace*.

[3] http://www.education-japan.org/peace/uni_list/9.pdf

[4] http://www.adachi-museum.or.jp

Figure 3 - The Cherry tree of Sakon at the Imperial Palace of Kyoto. Japan

The *Cherry tree of Sakon* is one of the most important Cherry of the *Imperal Palace*. Over the centuries in the royal palace hundreds of cherry trees have followed, and there is a great deal of attention in the way of succession over time. In my research I found out that in 1998 this tree was transplanted, it was 40 years-old. It had been waiting more than 25 years before its transplant. With the *tachibana orange tree of Ukkon* are both renewed through the Japanese history, but in the early days of the *Palace* primacy was given to the plum not the cherry tree. This change took place after a plum tree died in the mid-9th century. The emperor and nobles enjoyed *Hanamy*, flower viewing party, in the *Shishin-den* ceremonial hall since the *Heian* period.

Later, working at the School of Agriculture of the University of Reading[5], from 21 of May to 28 of October 2016, with Prof. Martin Lukac and Dr. Jake Bishop, developing a methodological work for an AgriClass[6] project in the South of France. This was a good occasion to study the methodological aspects of climate change and some important investigation about phenology of vine. It has concluded that climate change has, in the past 30 years, caused positive effects especially on the quality of the wine, for the anticipation of ripening and final characteristic of the fruit. The models developed in the AgriClass project by the Met Office show for the next 30 years an average overall increase of at least 1.5-2.5 °C in the annual temperature which could cause an advance in the phenological phases of about 6-22 days. At the same time, by 2050, the FAO estimates that demand for food will increase over 60% above the current situation (Wheeler

[5] https://www.reading.ac.uk/apd/

[6] hippos://agriclass.climate.copernicus.eu/

and Von Braun, 2013; Bailey, 2015). All of these considerations and experience have contributed significantly to the final elaboration of the thesis on returning to Sardinia in November 2016.
We had also the opportunity to visit the Cornwall and the new viticulture that is flourishing in England and contribute with Reading University to knowledge and the development of the wine-growing quality of the area[7].

[7] https://www.futurelearn.com/courses/climate-smart-agriculture/0/steps/26600

Objectives of study

The purpose of this thesis is to evaluate the effectiveness of the thermal time descriptor Normal Heat Hours (NHH), in a climate change context, applied to the description of the viticultural systems from the point of view of the close relationship between thermal resources and plant phenology. In particular the research studies the way in which NHH has changed over time and the potential future changes due to climate of the vine in Sardinia over the next thirty years regarding cultivation and consequently concerning modification of the rural landscape.

I) The first objective is to analyse historical daily temperature data to determine **if there is a trend of temperature change from 1951 to 2010 in Sardinia**. This is achieved through the analysis of historical meteorological and agro-meteorological datasets and for a reference period of at least 60 years, considering for example time series that start from 1951. Several factors were found to be of fundamental importance when making relevant considerations in the context of eventually climate changes. These factors ranged from the quality of dataset information, the lack of gaps in the historical dataset, the length of the time series, the list of the people who, over the decades, collect the measurement registered by the mechanical sensors, or the landscape changes due to a developing urbanised area around a general reference meteorological station.

II) The second is to **understand the impact of this potential climate change on viticulture through the application of NHH**. Since 1995 in Sardinia, by the network of automatic stations, we can calculate this index based on hourly data rather than on daily basis. Recent studies (Cola *et al*., 2012) show that models using NHH perform better than Degree-Day models, for all statistical indices tested and the dependent variables. Experimenting with different application methods of analysis, testing different thresholds, it is possible to conduct a specific case study in Nurra, a region of the north-western part of Sardinia.

III) The third objective is to **extend the level of the results** I, II, f**rom single points to larger areas**, in order to generate maps of the region of Sardinia by applying an appropriate geo-statistical methodology by using the Geographic Information Systems (GIS). The maps of meteorological data (i.e. temperatures, rainfalls) and agro-meteorological indices could enable us to understand how indices varied across the territory. To accomplish this goal it is essential to increase the current resolution of the maps and get an appropriate resolution to be able to make local evaluations.

IV) The fourth objective is **to analyse**, applying projected climate change, **a range of climate change scenarios to develop an understanding of what may happen in 2050 for the wine sector.** This will develop further understanding of the likely impact of projected climate change on the viticultural landscape, where the temperature increase may require, for instance, the migration of the vineyards from the coastal areas to the hills. The application of the scenarios would allow assessment of the state of viticulture 1951-2050: from 1951 to 2010 with real data, and from 2010 to 2050 with the simulations of climate and phenological scenarios. Furthermore, being able to work at a sufficiently detailed resolution to assess the local scale, to get the evaluation of "modification" of rural vineyards landscapes about possible climate change testing the calibrated phenological models, developed in this work by a real dataset, on the scenarios 2010-2050.

Introduction

Phenology

Floret prima omnium amygdala mense januario...

ab ea proximae florent armeniaca dein tuberes et praecoces.

Floret autem solstitio vitis.

Pliny the Elder (23-79 AD), Naturalis historia

In all civilisations, observations on the annual plant cycle have formed the basis for managing their cultivation. From China, Latin America, the Mediterranean, historians, botanists and agronomists have traced the knowledge of these specific rhythms for each species and environment. The first and longest phenological series in the world started in Japan on 800 d.c. (Aono *and Kazui.,* 2008), in figure 4.

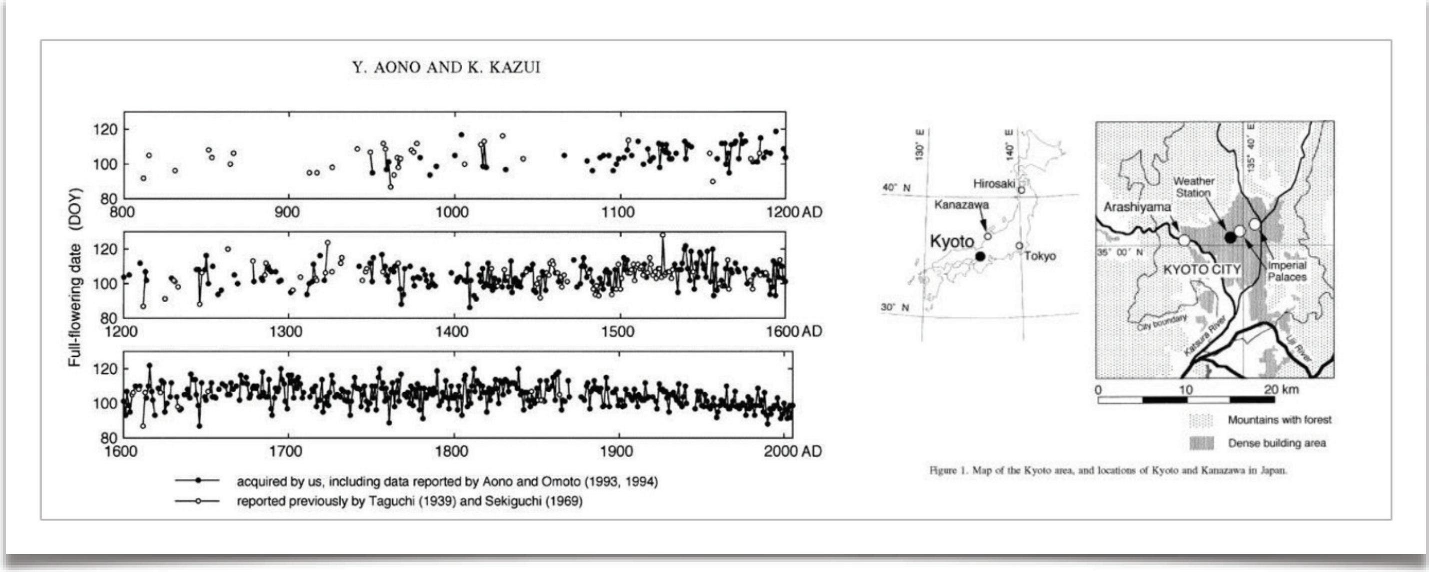

Figure 4 - Phenogram of the cherry bloom period during the ages in the Royal Palace, Kyoto

In every age, we find evidence of such knowledge. The UK naturalist Robert Marsham is considered to be the founding father of the modern phenology: in 1736 Marsham began a series of observations entitled: *27 Indications of Spring*. These observations were passed down through the Marsham family over generations (Priesnitz, 2008), and the observations were continued annually until 1958. In 1750, Linneo, former director of Upsala University in Sweden, began his phenological observations with the assistance of some 20 associates. The modern phenological Era that started in parallel with the scientific classification of the species (Puppi and Zanotti, 2009).

The etymology of the term derives, not for a case, from the Greek *phaino* which means "to appear" and *logos* which means "discourse" and was proposed for the first time in 1853 by Morren. It was very quickly adopted by other scientist. Instructions for the observation of periodical phenomena were printed in 1852 by the Royal Academy of Science and it inspired also the Bureau Central Météorologique of France, with the *Observation sur les phénomènes de la Végétation et sur les anumaux* (Hudson *et al*., 2009).

From 1840 to 1870, Quetelet, director of the Royal Observatory in Bruxelles, collected phenological data observed in many countries and collected datas from over 80 stations, in Italy too (Camuffo *and* *Jones*, 2002). In Italy the first observations belongs to Da Schio and Lampertico in 1873[8].

Phenology is an essential discipline in the environmental study of ecology which is extended on poikilothermic organisms and their phenological manifestations may concern plants and animals.

Phenologist studies from the individual level to the entire ecosystem, as we should observe as the manifestation of individual phenophases. For example the spring flowering of plants is the result of synchronisation between physiological processes, endogenous complex and abiotic factors, namely meteorological and those related to photoperiod. A clear trend among many temperate species, including birds, plants and insects, during the past decades is that they have entered reproductive phase earlier during the spring and summer, (Beebee, 1994; Walther *et al.*, 2002; Menzel, 2005; Parmesan and Galbraith, 2004).

Plants are the multicellular organism in which is characterised by an organised distribution of growth and by the organisation and differentiation of tissues. Some forces must exist through which cells mutually determine the location and type of growth and differentiation (Leopold, 1964; Odum, 1998). Growth is simply the production of biomass, and it typically occurs with the increase in the width of the stem or the limbs, length/height and weight.

Growth is fundamental in all organisms to reach those dimensions and forms that allow facing events in the fullness of survival opportunities. Plant growth analysis is an explanatory, holistic and integrative approach to interpreting plant shape and function (Hunt, 2002; Leopold,1964)

[8] http://www.parks.it/parchi.po.collina/giardino.fenologico.html

Development is that moment of the plant cycle in which there is a differentiation of organs and tissues, morphogenesis, which is governed by a complex interaction of vegetable hormones which, with the variation of their presence and concentration, respond to the stresses of the external environment. Plant-specific hormones play a central role during the cell cycle and influence numerous developmental programs (Meier, 1997; Werner *et al*., 2001).
Phenological phenomena can, therefore, be considered as complex responses that result from the integration of the genetic characteristics of the plants themselves with all the abiotic and biotic factors present in the environment where the plants themselves live and grow, in figure 5.

The development of the plant takes place continuously: every phenological phase evolves into the next, so the mere phases of phenomena are the physiological state that we arbitrarily consider important for its natural development. This assertion implies the need to divide the development into phases collected in more or less numerous and homogeneous classes of growing-development. Phenology is also included in a branch of bioclimatology, which deals with the study of biological rhythms about biotic and abiotic components and the interrelations between phases in the same or different species. The phenological events are the result of an interaction between the genes and the various external environmental factors, such as temperature, rainfall, and the photoperiod which can influence the occurrence of biological events as a sort of biological clock, figure 5 (Greenham and Mc Clung, 2015). Bud phenology, or timing, becomes an essential element to be considered when addressing the role of dormant buds on adventitious root formation (Smart *et al*., 2002). Among them, one of the most important is the circadian clock network, which comprises a series of interlocked feedback loops with transcriptional, post-transcriptional and post-translational regulation, like in this model of the A*rabidopsis thaliana* circadian clock (Greenham and Mc Clung, 2015)

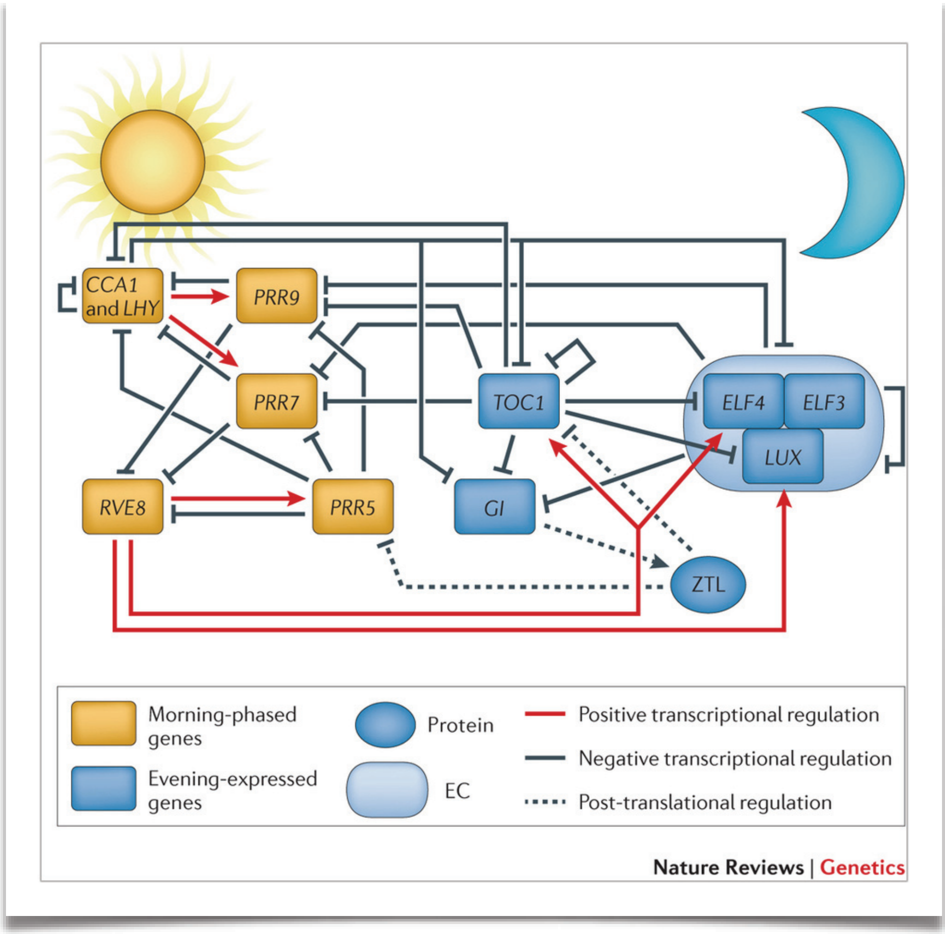

Figure 5 - Model of the *Arabidopsis thaliana* circadian clock

Phenology and agriculture

The current definition used by the scientific community of plant phenology, as studies of changing the life cycle phases of the plants in their effect during the year, has been proposed by Lieth (1970; Lieth, 1974), and has been resumed by numerous authors (Price and Water, 2000; Aerts *et al*., 2004; Studer *et al*., 2005; Cleland, 2007; IPCC, 2007; Dalle Fratte, 2010). Subsequently, the interdependencies with seasonal weather changes were specified.

In the last fifteen years, phenology has found new interest for the scientific community, initially for applications in studies of seasonal vegetation dynamics and on phenological models that can use data collected to predict capacity and productivity in certain agricultural regions, and later as a source of robust indicators of climate change in the medium and long term, as proposed by the European Topic Center on ETC-ACC of the European Environment Agency EEA.

Phenology is based on standards established by the World Meteorological Organization (WMO - 1494[9]), by the European and Mediterranean Plant Protection Organization (EPPO) and the Food and Agriculture Organization (FAO).

WMO considers phenological monitoring of plants since it is a reliable analysis tool for environmental monitoring that allows:

- to determine the consequences for the various spontaneous and cultivated species of variation of weather and climatic factors, verifying their effects;
- to verify the information base on which service statements are based, using phenological models, comparing data recorded by meteorological stations with model results and field data;
- to monitor the state of the environment, especially the effects of climate on plants, as well as to verify the effects of adverse meteorological events in the field;
- to monitor phytopathogens in order to reduce the use of pesticides and the dispersion of toxic pollutants into the atmosphere, even with the help of phenological modelling, comparing the data from models to assessing the possibility of plant protection interventions;

[9] http://www.wmo.int/pages/prog/wcp/wcdmp/documents/wmo-wcdmp-no70.pdf

- to provide to Sanitary system (es. Hospitals Local Services, ASL, in Italy) and the population with predictions on the pollen emission timing, in particular about the effects of amplitude or reduction in meteorological performance;
- to respond to the periodic requests made by the National, Regional and Local Authorities, Research Institutes, Regional Agencies;
- to improve the accuracy of weather analysis and forecasts made with agro-meteorological models;
- to support agronomic research and experimentation activities to produce new service products by implementing new phenological models with timely data of field stations in the field.

Phenological monitoring is also a key element in the study activities aimed at:

- to assess the climatic impact on ecological interactions, including the relevance of land management issues (agriculture, forests, invasive species), CO_2 flows, etc.;
- to carry out phytosociological analyzes of vegetation, always more timely and of strategic importance.

Phenological scales

The possibility of making observations and surveys on spontaneous and cultivated plants is possible in a standardised and univocal way through phenological scales. Each scale encodes the phenomenon to be recorded (i.e. germination, sprouting, leaf fall, etc.) and provides reproducible, generally nondestructive techniques for making the same observations. (Marletto *et al*., 1999; Marletto *et al*., 1993). Careful observation of the plant cycle has resulted in some coding rules:

- the hierarchical prevalence and incidence of the most recent stages, as it is frequent the gradual manifestation of the process and the simultaneous presence of several phases;
- the numerical prevalence of individuals in the stadium considered, for example, or the latest stage that interests more than 50% of the observation units;
- the minimum threshold, set for assessing the achievement of the last phenophase of a minimum threshold of detected units, for example greater than 10% of the population.

The Biologische Bundesanstalt, the Bundessortenamt und CHemische Industrie (BBCH[10]) scale has been universally set up as a scale to describe the phenological development states into monocotyledonous and dicotyledonous species. The BBCH-scale, that uses a decimal code system, divided into principal and secondary growth stages, is a system designed to encode phenological stages of similar development uniformly. The structure allows for enclosing all existing scales, furthermore, it is possible to adapt it to new species of interest for which in the past have not been designed development scales.

[10] German Federal Biological Research Center for Agriculture and Forestry (BBA); German Federal Office of Plant Varieties (BSA); German Agrochemical Association (IVA); Institute for Vegetables and Ornamentals in Grossbeeren / Erfurt, Germany (IGZ).

Phenology and grape

The knowledge of the annual timing of phenophases and their variation can help to improve crop management with leading to higher and more stable crop yields and improved food quality and it is also used to define the growing season length in a region (Chmielewski, 2001).

Tanzer defines Terroir as the set of all environmental factors that affect a crop's phenotype, including unique environment contexts, farming practices and a crop's specific growth habitat; it means that the terroir represents how a particular region's climate, soils, terrain, influences the taste of wine (Tanzer *et al.*, 2007; Neustadt *et al.*, 2000) .

In his books, Fregoni also defines terroir as the interaction between vine, climate and environment (Fregoni, 2003). In addition to climatic and climatic factors, of course, the soil's influence on wine composition and quality also plays a primary role (Seguin, 1986; Van Leeuwen *et al.*, 2004; Van Leeuwen, 2010; Reynolds and De Savigny, 2016).

Each biotype of each genotype and the inner ring shows a distinct phenological behaviour that also varies depending on the pedo-climatic environment.

Among the factors that affect the development of the vine, the climate is certainly the most visible and studied aspect. This doctoral dissertation will also explore the relationship between vine phenology and climatic factors and particular temperature dynamics.

(Tonietto and Carbonneau, 2004; Boselli *et al.*, 1992; Morlat e Bodin, 2006). The climate is the factor that most influences the diversity of cultivated varieties. Below are the main criticalities suffered by the vine due to climatic factors. At temperatures between 15 and 30 °C, there is a positive linear correlation between temperature and photosynthesis; on the contrary between 30-45 °C, there is a negative correlation; net photosynthesis decreases when temperatures exceed 30 °C and there is progressively a rapid degradation of enzymes and chlorophyll; at 47 °C photosynthesis stops definitely. The optimum temperature for photosynthesis is between 22 and 27 °C, (Kliewer, 1968; Kliewer and Lider, 1968; Ferrini *et al.*, 1995). During ripening, temperatures from 30 °C to 35 °C reduce the number of total soluble solids also, high temperatures around 35 °C significantly decrease the formation of anthocyanins (Kliewer, 1971; Kliewer, 1973).

The high temperatures of the berries greater than 37 °C; and of the leaves (greater than 42 °C; (Kliewer and Lider, 1968) have a negative effect on the accumulation of sugars and photosynthesis. Several studies have shown that sun exposed grapes reach temperatures higher than 7 °C compared to air temperatures and 10 °C higher than shrimp grains (Bergqvist *et al.*, 2001). Lower temperatures are not dangerous in Sardinia, (Hendrickson, 2004).

Photosynthetically active radiation, (PAR), designates the spectral range that plants are able to use in the process of photosynthesis. It affects the budding, the bloom and the maturation dates, as well as the phenolic maturation (Failla *et al*., 2004; Terashima *et al.*, 2009).

Rainfall is a major factor that affect growth and phenology, also considering that a substantial part of Mediterranean viticulture is located in areas with low rainfall and water deficiency extended to most of the vegetative season (De Palma *et al.*, 2000). Excessive rains during ripening cause bunching of the bunch. As cultivated species, water deficits are easily compensated by rescue irrigation systems, also envisaged by the production disciplines of European wine-growing areas (Mercenaro and Nieddu, 2006).

The wind reduces photosynthesis and total soluble solids (Kobriger *et al*., 1984; Jackson and Lombard, 1993).

The aromatic qualities of wine vary according to the cultivar, the physiological stage of the vine, the pedoclimatic and microclimatic conditions (Hunter, 1991; Jackson and Lombard, 1993; van Leeuwen *et al*., 2004; Mori *et al*., 2005).

Phenological scales adapted to describe grape

The phenological reference scales for Vitis *vinifera* L., 1753, are described in three different morphological scales:

• Baggiolini, proposed in 1952;

• Eichorn and Lorenz in 1977;

• the BBCH scale, previously described, and adapted to the vine by Lorenz *et al.* (1995).

Baggiolini was a swiss phitopatologist and he initially related phenology of grapes (10 phases) to grapevine patogens like Plaspmopara viticola. The missing phenological phases were added in 1993, adding six stages of growth similar to those suggested by Peterson (1984) and subsequently described by Coombe using letters from A to P without intermediate levels of development. This limit reduced its use in research projects in the 1990s and beyond (McIntyre, 1982). Eichhorn and Lorenz in 1977, later modified by Coombe in 1995, proposed 22 stages of phenological phenomena, from the winter bud to the fall of the last leaf. The scale uses a string of 47 numbers with jumps that allowed the insertion of intermediate stages. The BBCH vine had two modifications, one by Lorenz in 1995 and one subsequent by Failla (2004). In the BBCH of the vine there are: development of the bud; leaf development; inflorescence; flowering; fruit development; ripening fruit; senescence, in figure 6.

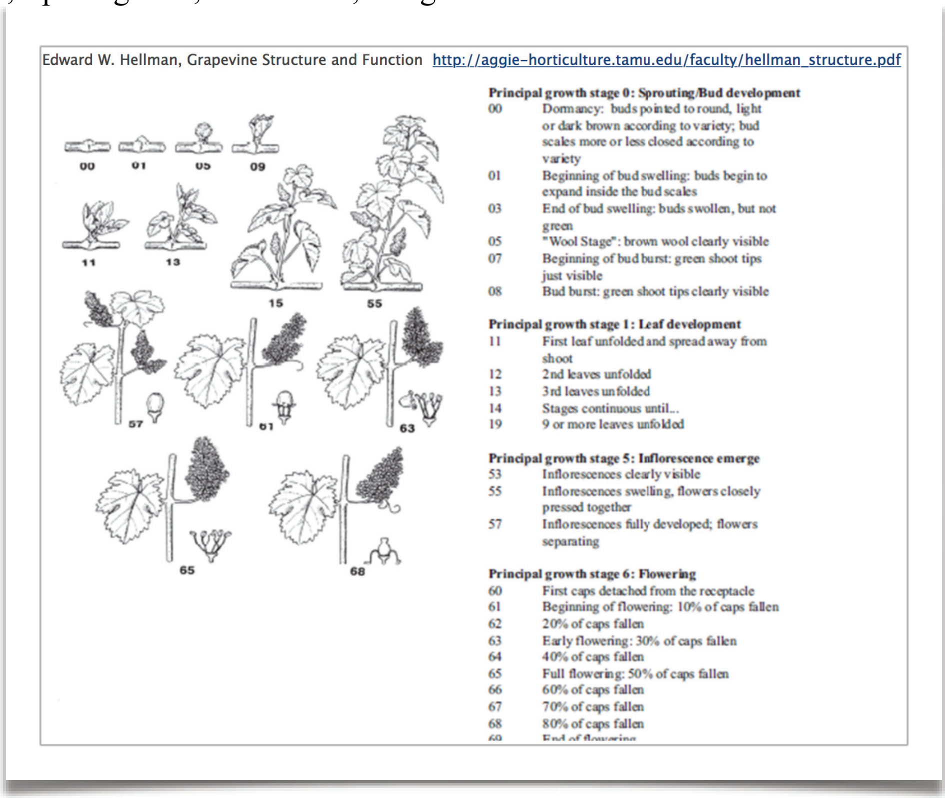

Figure 6 - Main phases of BBCH grapevine

Plant Phenology as a Biomonitor for Climate Change

During the Roman Empire *Lucious Ostilius* wrote a treatise on agronomy which explained that in the Northern Italy climate was changed, if compared with the earlier centuries, so that lush vineyards and olive groves flourished there in his time. It was reported also in the book I of *De re rustica*, by Columella, in 1515 (Iafrate *et al*., 2017). We have many samples of this during the ages until arrive to the modern age. Schmidt in 2014 defines, in a series of studies on Germany dataset, plant phenology as a biomonitor for climate change (Schmidt *et al.,* 2014; Kramer, 1995; Kramer; Koch *et al.*, 1996).

Climate-related flowering phenology has attracted growing concerns due to its unique contribution to innovative theory and application of plant phenology at the global scale. Recent studies confirm that with the change in climate, flowering duration has tended to be prolonged, mainly due to higher temperature sensitivity and greater advancement at the beginning of flowering rather than the ending of flowering (Fei *et al.*, 2017; Zhao, 2013).

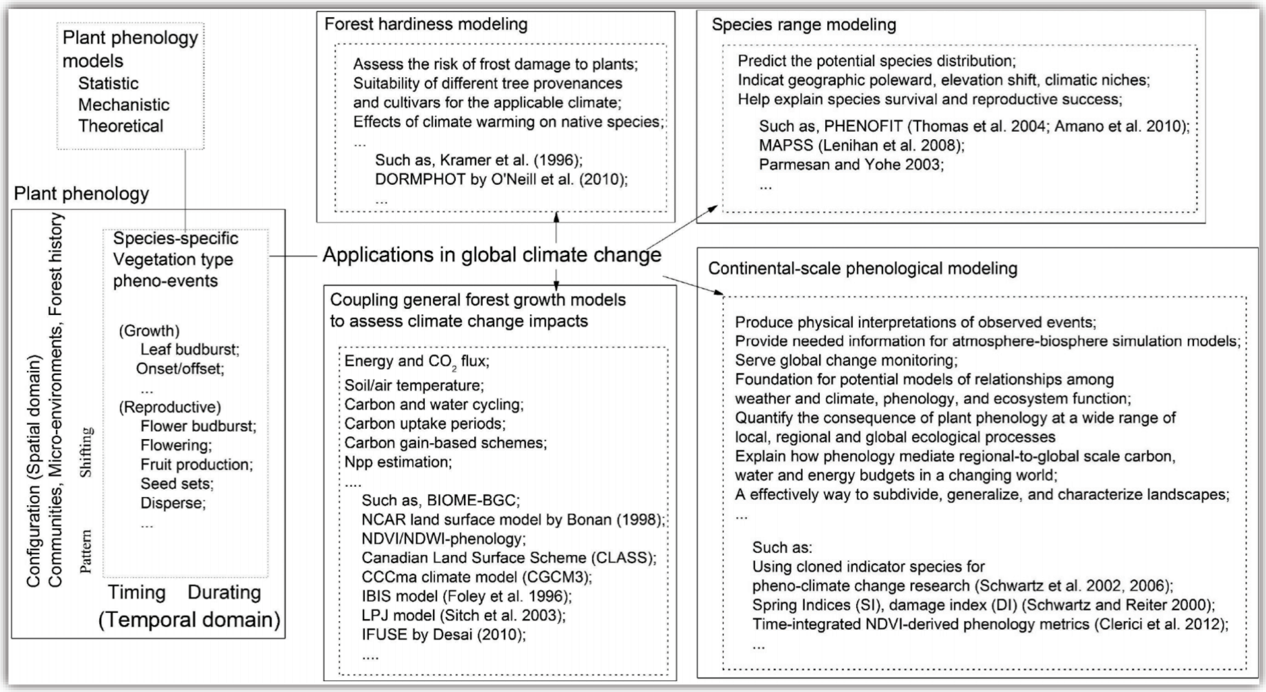

Figure 7 - State of the art of phenology as a biomonitor for climate change

In 2013 Zhao synthesised the algorithmic realisation of the "phenology-climate" connection in the triangular diagram, in figure 8, has become a crucial tool for ecological and climate researchers to quantify phenological responses to climatic drivers and a way in which to gather potential feedback of phenological changes caused by climate change (Cleland *et al.* 2007; Zhao *et al.* 2013; Van Vliet, 2014).

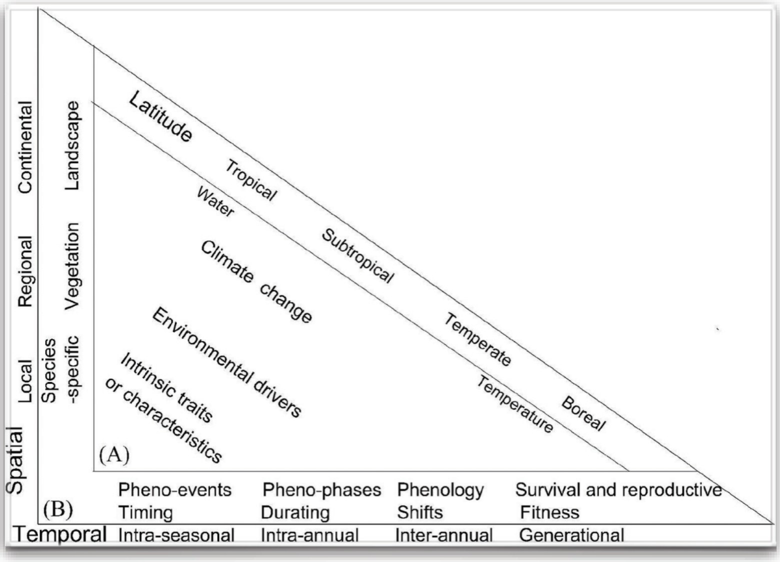

Figure 8 - Factors controlling plant phenology

Framework of phenology–climate interactions: (A) inside triangle shows the affecting components and factors to controlling plant phenology as a perspective of study; (B) outside triangle displays the tempo-spatial dimension of plant phenology to address all scale issues related to plant (trees for consideration).

A clear trend among many temperate species, including birds, plants and insects, during the past decades is that they have started to reproduce earlier during the spring and summer (Sparks, 1999; Walther *et al*., 2002; Parmesan and Galbraith, 2004; Wolf, 2005; Scheifinger *et al*., 2005; Menzel, 2005; Navarro-Cano *et al.*, 2015). Relative calendar timing followed the expected latitudinal trends, with earliest bud-break and bloom dates observed at the southernmost sites (Andris *et al*.,1985). One of the consequences of climate change related to temperature increase is a shift of some phenological stages to earlier times during the season, also in the Toth-Lences experience in Hungary for some Hungarian grapes cultivar (Toth-Lences *et al*., 2015).

A study on over 1500 plant phenological observations of 320 plant species based on network data, changes in climate explains on average 66 % of the variation in timing of phenological events from year to year (Van Vliet, 2014). Recently showed changes in time of first flowering with climate changes (Parmesan and Hanley, 2015).

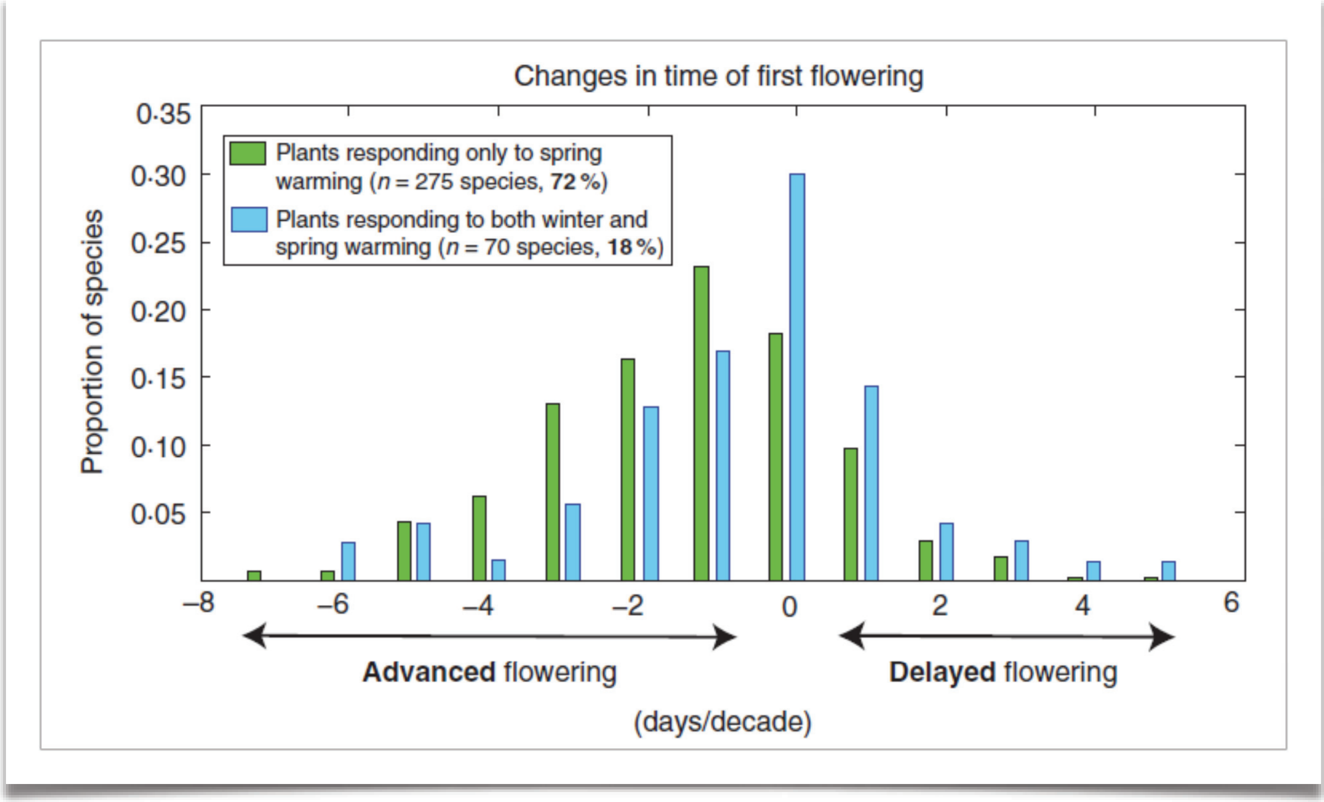

Figure 9 - Overview of five major global meta-analyses from long-term observational data

The analysis of Parmisan is on individual wild species with diverse distributions in terrestrial (T), marine (M) and freshwater (F) systems, including datas from multiple continents and oceans for each case of study (Poloczanska, 2013). Percentages are approximate and estimated for the studies as whole-individual analyses within the studies may differ. The specific metrics of climate change analysed for associations with biological change vary somewhat across studies, but most use changes in local or regional temperatures (e.g. mean monthly temperature or mean annual temperature), with some using precipitation metrics (e.g. total annual rainfall). Individual species were analysed (Rosenzweig and Parry*, 1994*; Rosenzweig *et al., 2008*).

Study	Number of species and functional groups	Species in given system (% of all)			Plants in each system (% of each system)			Species showing significant long-term change in phenologies, distributions, abundances or morphology (% of all)	Changes consistent with local or regional climate change (% of species that showed change)
		T	M	F	T	M	F		
Parmesan and Yohe 2003	1598	85	13	<2	63	0	0	59	84[1]
Root *et al.* 2003	1468	94	5	<1	49	<1	<1	40	82[1]
Root *et al.* 2005	130	100	0	0	65	0	0	100	92[1]
Rosenzweig *et al.* 2008	55 studies	65	13	22	44	14	42	–	90[2]
Poloczanska *et al.* 2013	857	0	100	0	0	16	0	76	83[1]

Figure 10 - Main results of nearly 4000 studies of phenology and climate change[11]

[11] https://academic.oup.com/aob/article/116/6/849/162145/Plants-and-climate-change-complexities-and

Phenology and climate change

Phenology is perhaps the simplest process that tracks changes in the ecology of species in response to climate change (IPCC, 2007).

The impacts of climate change on plant systems include changes in the spatial distribution, floristic composition, structure, phenology of species and whole plant communities (Forrest *et al.*, 2010; Dalla Fratte, 2010).

In the last twenty years, the role of phenology in ecology and evolution about climate change has grown. Phenological shifts have been among the most obvious and thoroughly documented biological responses to the climate warming of the last 150 years[12] (Beebee, 1994; Myneni *et al.*, 1997; Fitter, 2002; Parmesan and Yohe, 2003; Forrest *et al.*, 2010).

EEA and IPCC

According to the definition used by the United Nations Framework Convention on Climate Change (UNFCCC), climate change refers to a change, superior to the natural climate variability observed over comparable periods of time, of the state of the climate; such variation is attributed to an alteration in the composition of the global atmosphere by human activity.

The European Union governs the issue of climate change through the EEA, the European Environmental Agency. It was established by Council Directive 1210/1990 and amended by the EEC Directive 933/1999. Among the most relevant documents, the White Paper "Adapting to Climate Change: Towards a European Framework for Action", presented by the European Commission on 1th April 2009. It illustrated action to make the European Union less vulnerable to climate change. Many others came after, in these reports, the concepts of vulnerability and resilience are defined and repeated. The vulnerability is expressed as the sensitivity level of a system with the adverse effects of climate change such as speed in climate variability and extreme events. Resilience, however, is very close to the concept of homeostasis and is defined by the IPCC as the ability of the same system to absorb perturbations while maintaining the same structure and basic operating modes.

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[12] http://rstb.royalsocietypublishing.org/content/365/1555/3101

Climate change adaptation policies are defined as proactive when they have not limited to analyse the impact of changes but to highlight the opportunities that come from them to innovate processes, technologies and governance.
In Europe, the most vulnerable areas according to the EEA 2008 data are southern Europe, the Mediterranean basin, peripheral regions, Artide, mountainous regions, and in particular the Alps, island areas, coastal and urban areas.

Intergovernmental Panel on Climate Change, (IPCC), was formed in 1988 by the World Meteorological Organization, WMO, and the United Nations Environment Program, UNEP, to study the global warming phenomenon. The IPCC does not directly carry out scientific research but analyzes the scientific literature published by *peer review*, and select and evaluate research articles or research projects proposed by the scientific community to verify their eligibility for publication or funding.
The IPCC periodically publishes evaluations of the scientific, technological and socio-economic documentation produced to understand the climate change, impacts and mitigation and adaptation alternatives available.
The first Valuation Report was published in 1990, the second in 1995, the third in 2001, the fourth in 2007 and the last in 2014. These reports were used as a basis for world agreements, including the Framework Convention of the Nations United in 1992 establishing "common but differentiated responsibilities"; the Kyoto Protocol of 1997, the Paris Conference of 2015, in which 190 governments following IPCC reports have signed that climate change exists and is caused by man and is therefore somewhat containable.

Climate change scenarios

The impact of climate change on the environment for causes that we can call anthropic, especially on the concentration of carbon dioxide, is very complex, (Gallo, 2015).

Many future "climatic scenarios" have been hypothesised to describe the various processes that will characterise the human-based environmental and operational climate system to understand what can happen in the next few decades and to verify the effectiveness of mitigation and adaptation strategies. The most recent scenarios were presented in the latest IPCC report.

Emissions scenarios[13]*, 1990s*

- *Emissions scenario*s describe future releases to the atmosphere of greenhouse gases, aerosols, and other pollutants and, along with information on land use and land cover, provide inputs to climate models[14].
- *Climate scenarios* are plausible representations of future climate conditions (temperatures, precipitation, and other aspects of climate such as extreme events). *Vulnerability scenarios; s*ecurities of demographic, economic, political, cultural and institutional characteristics are needed for assessing the potential to be affected by changes in climate as well as for examining how future patterns of economic growth and social change affect vulnerability and capacity to adapt[15].
- *Narratives scenarios;* while some socioeconomic factors affecting emissions and vulnerability are quantitatively modelled, others (eg, political, institutional, and cultural factors) are not effectively quantified[16].

- Over time, scientific research, governments, international working groups, and the most prestigious Research Centers have developed new scenarios that incorporate new economic, environmental and technological information, at a spatial and temporal resolution (Moss *et al.*, 2010, Grillo, 2015).

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[13] http://sedac.ciesin.columbia.edu/ddc/ar5_scenario_process/scenario_background.html

[14] http://sedac.ciesin.columbia.edu/ddc/ar5_scenario_process/scenario_background.html

[15] http://sedac.ciesin.columbia.edu/ddc/ar5_scenario_process/scenario_background.html

[16] http://sedac.ciesin.columbia.edu/ddc/ar5_scenario_process/scenario_background.html

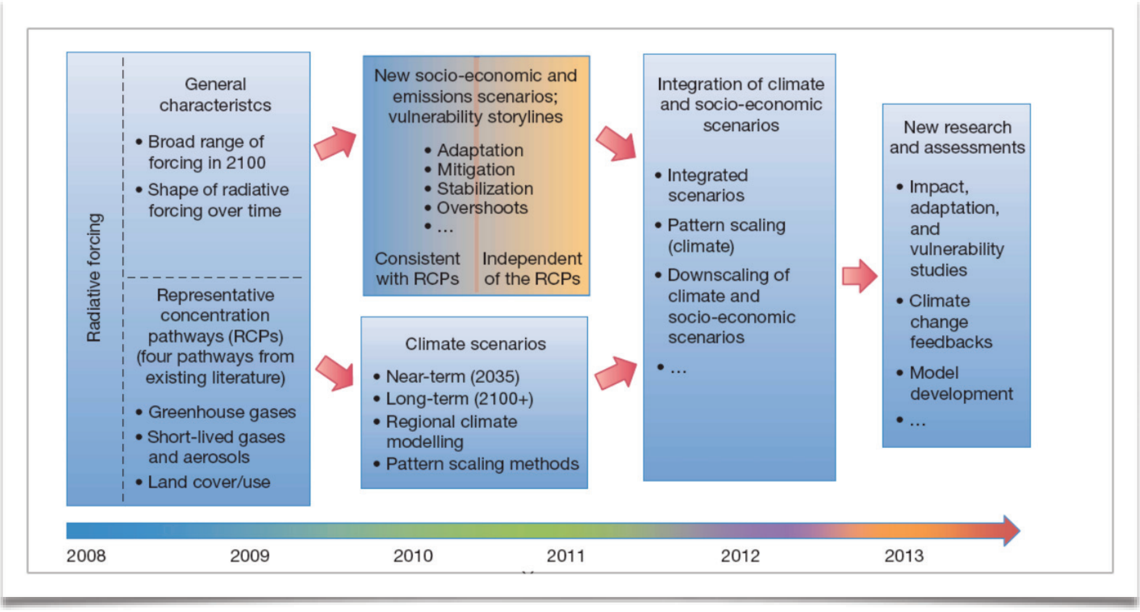


Figure 11 - Moss synthesis of parallel approach developmenting new scenarios

It has moved from sequential characterisation to a more evolved parallel approach (Moss, 2010). These radiative forcing trajectories were thus defined Representative Concentration Pathways, RCPs. RCPs are due to different combinations of economic factors, technological, demographic, political, with precise and diversified goals, and have been universally recognized as newly-defined scenarios (Moss *et al.*, 2008; Van Vuuren *et al.*, 2011).

Following an IPCC selection, four levels of RCPs were selected in 2007. They were selected for scientific purposes to represent the span of radiative forcing literature:

- *RCP 2.6*: a low level of forcing with low greenhouse gas concentration levels developed by the Netherlands Environmental Assessment Agency;
- *RCP 4.5*: a mid-level scenario developed by the MiniCAM modelling team at the Pacific Northwest National Laboratory's Joint Global Change Research Institute;
- *RCP 6*: a second medium-level scenario developed by the AIM modelling team at the National Institute for Environmental Studies (NIES), Japan;
- *RCP8.5*: a more advanced, very high scenario developed by the MESSAGE team and the IIASA Integrated Assessment Framework at the International Institute for Applied Systems Analysis (IIASA), Austria;

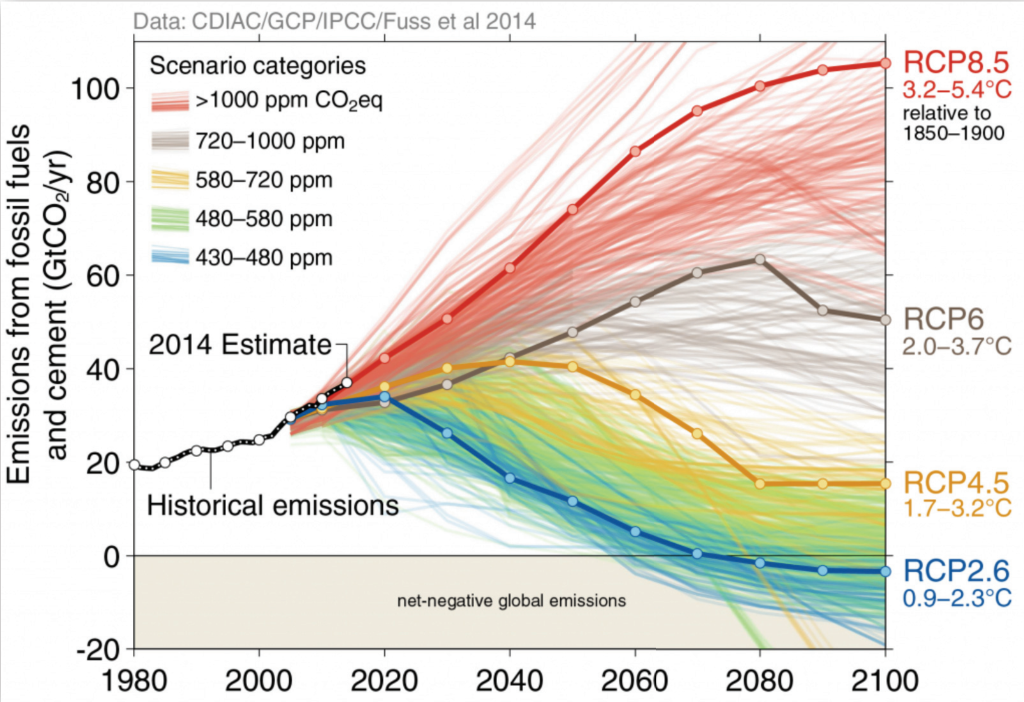
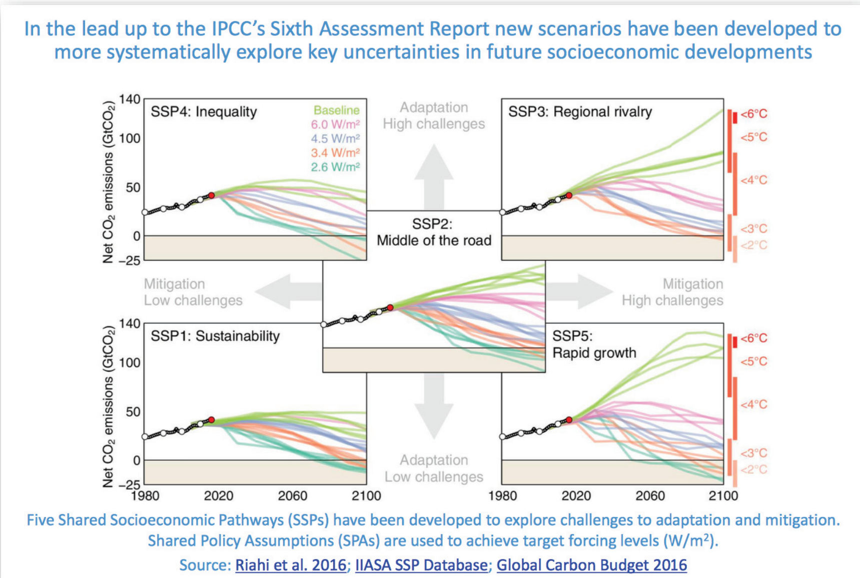


Figure 12 - Main scheme of IPCC's fifth assessment outlines for future scenarios RCP2.6, RCP4.5, RCP6, and RCP8.5[17] — for carbon dioxide emissions from fossil fuels and cement. The black line marks our former choices. The red line — RCP8.5 — represents what will happen if habits don't change. (Fuss *et al.*, 2014)

Over the last few decades the weight of CO_2 producers has changed. The EU's ecological policy shows the results. While the EU has declared and planned and respected its emissions objectives in the various international treaties that have followed, such as Kyoto, Paris, many other countries have not adhered to and, without going into the political aspects of this accession, it represent the greatest uncertainty as regards the future scenarios. The increasing weight of these countries is evident in figure 14.



[17] http://www.globalcarbonproject.org

Figure 13 - Other relevant aspects of IPCC's fifth assessment outlines for future scenarios

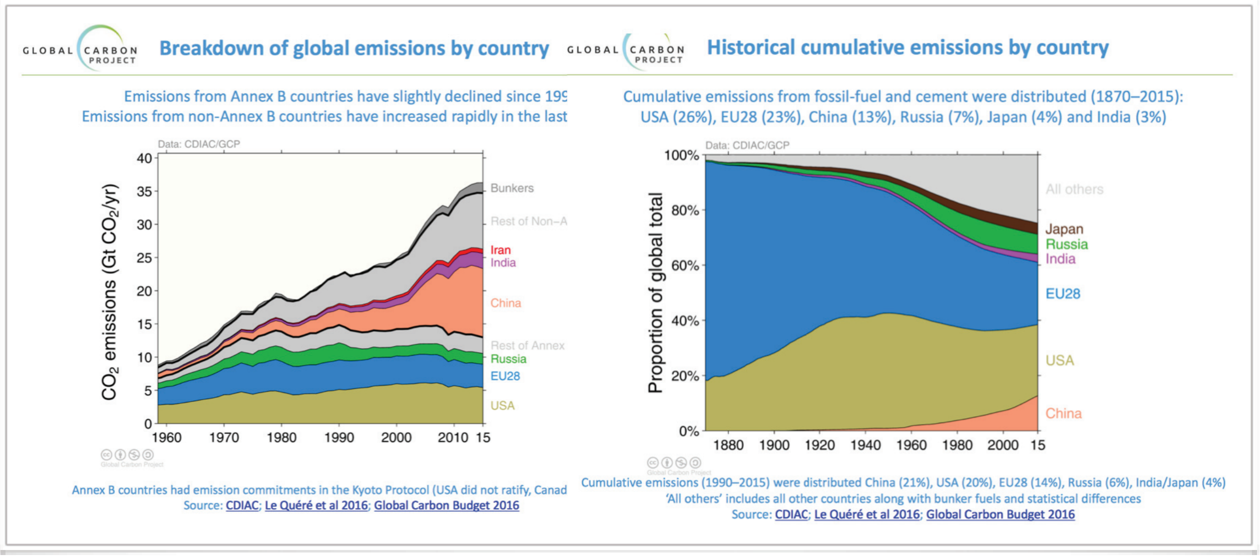


Figure 14 - Evolution of the roles of different countries in global emission

About the different scenarios, the increase in temperatures, it leads to a direct effect on the production of CO_2 on plants (Bindi *et al*., 1996), caused by a greater accumulation of dry matter, a higher nitrogen consumption, higher water consumption and a reduction in soil water reserves, a phenomenal advance that makes plants vulnerable to late frosts and thermal swings, raises competition with crop pests. Thus, the productive cycle is overly variable, the cultivation area is discussed, as well as the proliferation of insects that winter at a critical temperature above the abatement threshold.

Even abnormal precipitation and intensity abnormalities have significant impacts on the agricultural system, resulting in greater erosion, slow decomposition of organic matter and hydrogeological risk.

Direct effects of climate changes concerns the health status of plant and animal species, variations in the productivity of pastures and forage crops, agricultural rotations, nutrient losses due to excessive biomass production, which indirectly affect the costs of agricultural products and food availability. The contribution that agriculture can provide to mitigating climate change is dependent on:

- the adoption of agricultural practices that favour the sequestration of carbon into biomass, in the case of tree crops, and in her, in the case of herbaceous crops;
- the supply of biomass for energy purposes in place of fossil fuels, reductions in CO_2 emissions and greenhouse gases.

Essential elements of Mitigation are:

The conservation of forests, which are a clear mitigation option, requires that a forestry policy is established at international level to enable forestry credits in the context of biomass growth for energy. The Reducing Emissions from Deforestation and Degradation of Forests, (REDD+), which is based on the establishment of a payment system for developing countries demonstrating the ability to reduce emissions from forest degradation and deforestation a tight debate has been going on over the last few years to avoid speculations on this subject too, which is closely linked to the general concept of reforestation, which generates carbon sequestration in favour of biomass production. The European Union intends, by 2013, to set up a global forest carbon mechanism, the Global Forest Carbon Mechanism, the GFCM, and to include credits from forestry activities in the European Carbon Credit Market (EU-Emissions Trading Scheme). All this will be experienced during a pilot phase that will test the mechanism and will authorise the purchase of REDDs to achieve the reduction targets by the end of 2012. At the end of this initial phase, one might consider the possibility of authorising businesses to use these credits to offset part of their emissions after 2020.

Forestry management and wood products, which are the main source of income for timber, but mainly byproducts (e.i. pellets), which are increasingly able to provide complementary income that is essential for the sustainability of forestry activity in the long period.

Sustainable agriculture, also called eco-compatible, which, in addition to producing food and other agricultural products, is also economically advantageous for farmers, while at the same time committed to carrying out a non-intensive, environmentally friendly production cycle with a small use of pesticides, helping to improve the food quality of the entire company.

General Circulation and Regional Climate Models

The general pattern of circulation, often abbreviated as GCM from the acronym of English General Circulation Model, is a type of climate model used in climate predictions to understand the climate and predict future climate change. These models simulate physical processes occurring in various components of the climatic system (atmosphere, ocean, cryosphere, and terrestrial surface) in response to increasing greenhouse gas concentrations.

Despite the progress in recent years, GCMs have a too low resolution for their use in assessing climate change impacts. A source of uncertainty in the application of GCM for simulations based on future climate scenarios is the fact that different physical processes (eg cloud-related and storm-related processes) can not be adequately modelled because they occur at smaller scales. Therefore, to make numerical simulation possible, you have to parameterise the effects of these processes in the short term and thus consider the average of their known large-scale properties.

Small territories, such as islands, are very complex to modernize as local weather moods and physical processes are very variable within the same. These forcibly can not be accurately represented in the GCM projections for the reduced spatial resolution they provide, which makes them inadequate to assess the impacts of climate change in farming at the local level for this significant limit of resolution. An island like Sardinia would be seen within 2 or 3 pixels. Therefore, the local climate can not be fully reproduced by GCM, resulting in significant differences in impact studies at different scales (Gallo, 2015).

The dynamic downscaling technique and the methods used to increase resolution are therefore relevant. The output of the GCM with a resolution of 100 to 200 km defines the conditions for downscaling up to about 10 km by obtaining a Regional Climate Model RCM. The reliability of RCM projections depends on the GCM in question. Data processing is a very long and therefore costly process, and RCM's research developers take years to realize it. (Gallo, 2015).

The case study of Sardinia

Phenology and geobotanic in Sardinia

The geobotanical representation of plant communities concerning the environment and allows the description of the mesoclimes, or similar territorial areas of a region where we expect to find a homogeneous climate (Surano, 2005).

Sardinia has an irregular orography and high mesoclimatic variability, and for this reason, the final bioclimatic paper obtained according to the Worldwide Bioclimatic Classification System (WBCS; Rivas, 2005) has 43 classes of Isobioclime (Canu *et al.*, 2015), figure 15.

The most prominent isobioclimates are mesomediterranean ones: the lower Mesomediterraneus, the Lower Submarine, the weak eu Oceanic covers 22% of the total area and extends into the hilly areas of the whole region, particularly the settlements. The inferior, upper, oceanic, weak, lower Mediterranean vegetation extends for a total of 20.5% of the total surface. The third type of bioclimatic in terms of the amount of surface covered is the upper Thermomediterranean, the upper dry, weak eoceanic, which reaches 12.4%, and extends predominantly in the southern areas. Sardinia is also classified as C2 area among the regional areas of the wine-growing areas.

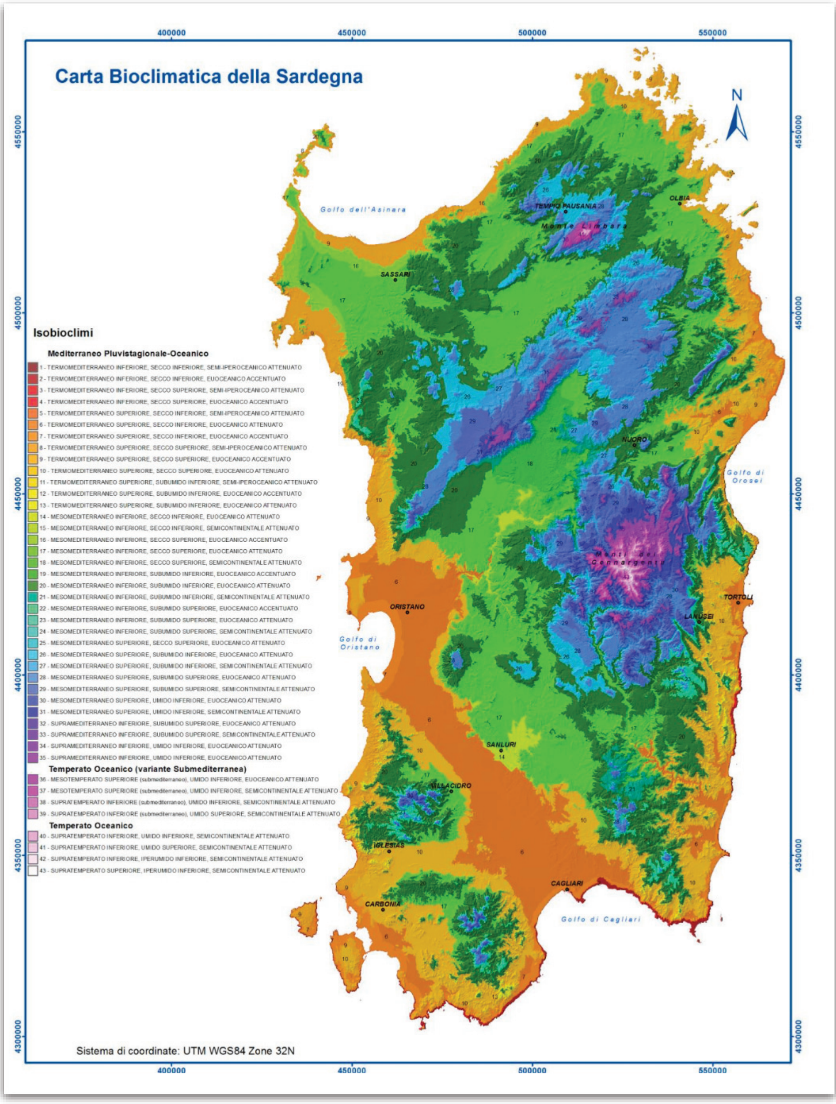


Figure 15 - Bioclimatic map of Sardinia

Vineyards of Sardinia

Sardinia, the second largest Mediterranean island, highlights many common traits with surrounding regions, but also some specific geographical, geological, climatic, vegetation, historical, cultural which are interconnected and are reflected in the modern wine growing. Sardinia has a surface of 24.000 km_2 between 38° and 41° of latitude with a coastline over 1800 km long. Orography is irregular: in a few tens of kilometers, it passes from coastal plains to hills and mountain reliefs also of some significance, Gennargentu massif, 1800 m, Monte Limbara 1350 m. Mountainous areas represent 13% of the whole regional territory; open plan areas represent 18% of the island. Being the island in the centre of the Mediterranean has allowed, over time, continuous exchanges, but also a prolonged isolation and a strong influence by the sea and the winds, in particular, the Mistral from the north-west, called in Italian "Maestrale." This resulted in a high chance of preservation of the cultures and traditional resources, but also harder for many of its products to be known outside.

Currently in Sardinia wine viticulture affects a total area of just over 27,000 hectares falling sharply and continuously compared to past decades, when the cultivated area exceeded 70,000 hectares. as showed in the map with the red points.

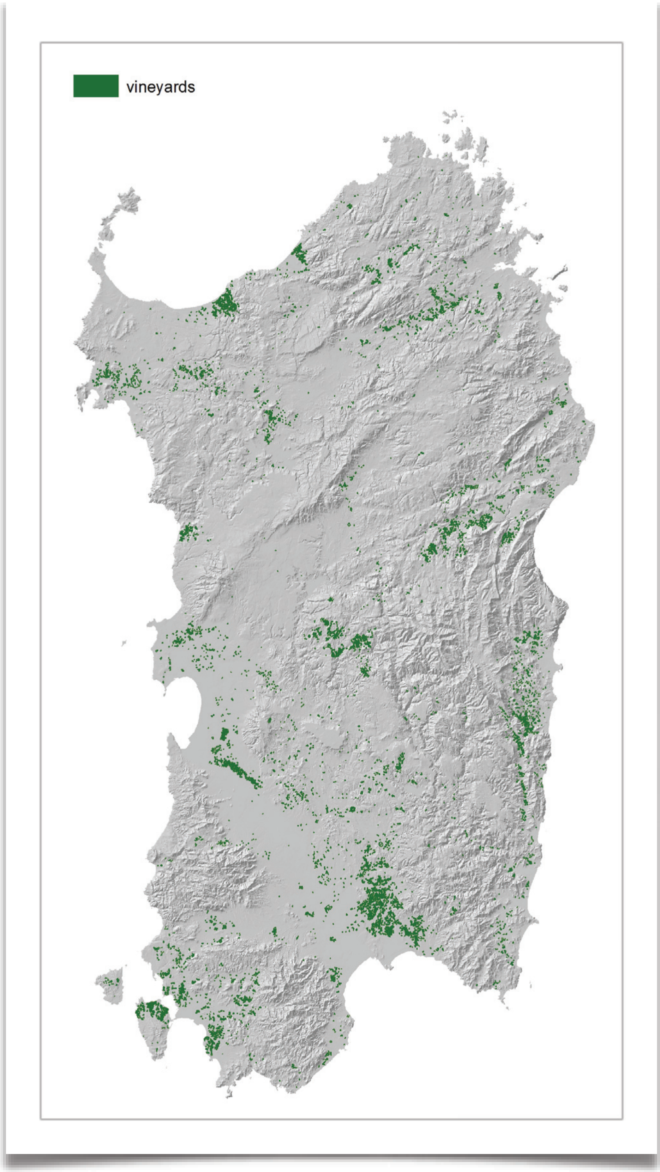


Figure 16 - Sardinia vineyards

Consequently, the international crisis in the sector and UE policies on incentives for explants had, in fact, witnessed a sharp decline of hectares (1974: 74,000 ha; 1984: 64,000 ha; 1994: 44,015 ha; 2004: 31,158 ha; 2014: 27148 ha) (Laore[18] data, 2015).

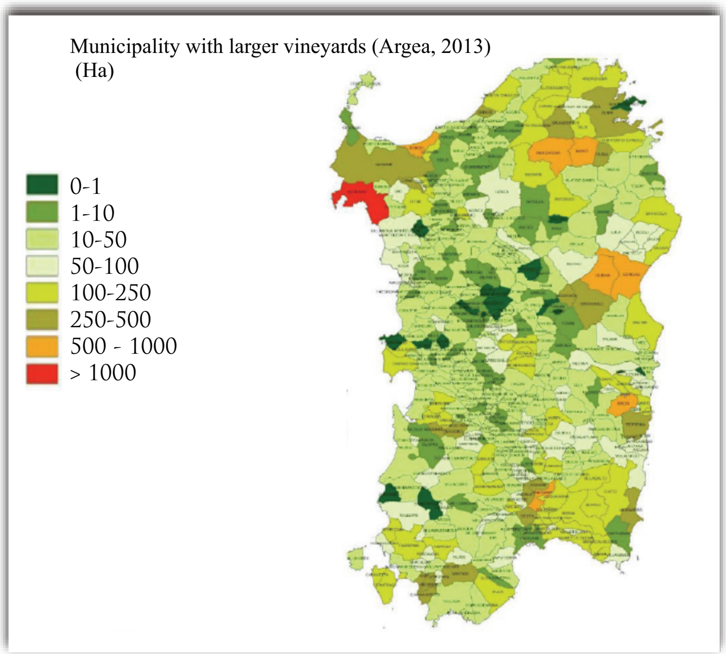
year	hectares of vineyards
1974	74000
1984	64000
1994	44015
2004	31158
2014	27148

Figure 17 - Evolution of vineyard in Sardinia between 1974 and 2014

The cultivation has spread throughout the island, with large differences depending on soil and climatic characteristics that differentiate the territory and more specifically we will represent in the following pages, treating the case study on the Nurra. The vine is more present in the coasts than inland, as it is more common to find vineyards in flat ranges (<300 m; 61%) or hilly (between 300 and 600 m above sea level 32%). The mountain vineyards represent, with 2195 ha, 8.4% of the local vineyard and are characterised by an average acreage much lower than the regional (00:19 ha against 0.73 ha). Currently, the grapevine is present in all four historic provinces of the island and is more cultivated in the province of Cagliari (9647 ha), followed, in order of implanted surface, Sassari (7647 ha), Nuoro (6636 ha) and Oristano (3070 ha). The application of various viticultural models, therefore, varies as a function of the diversity of environments and its climatic factors as the distance from the sea, the wind, the intensity and quality of light and the incidence of the Mediterranean vegetation surrounding the vineyard. All these factors, along with the human one, can help you identify the wine pairing and territory and to transmit to the vine and wine highly typical features providing additional value and income of the companies. The registered vineyards are now 26600 (Nieddu, 2004) with an average planted area of 0.73 ha; within these, the certified organic vineyards are about 3% of the total area. In Sardinia are active 23 winemaking cooperatives, who work less than currently 40% of the grapes produced in the region (4 in the Province of Oristano, 9 in the Province of Cagliari, 6 in the

[18] http://www.sardegnaagricoltura.it/assistenzatecnica/laore/

Province of Nuoro, in the Province of Sassari 4) 140 are private companies, which in recent decades have greatly increased in number and importance, considering that in the 70 private Enopoli worked just over 30% of the wine production in Sardinia. The vineyard restructuring has also resulted from an increase in the production of quality wines (DOCG, DOC and IGT) today extend over 13,313 ha (Vineyard register Agea[19], 2013). DOC means Controlled Denomination guarantied. DOCG means Controlled Denomination guarantied and certified. IGT means Indication o typical Geographic origins. They are indications of quality for the consumers in the global market. The vineyards DOC and DOCG are mainly concentrated in the northern part and Western (Oristano).



The province of Oristano, in particular, is primarily geared to the production of DOC and DOCG wines, since over 90% of the vineyards found there belongs to this category. In the province of Cagliari, in turn, it seems to prevail the production of table wines and/or table grapes, since only a small part of the wine-growing areas are to belong to a DOC.

Figure 18 - Municipalities (city hall districts) with larger vineyards

They are active 7 *Consortia* (Wines of Sardinia, Cagliari Wines, Carignano del Sulcis DOC Alghero and Sorso -Sennori, Cannonau, Vermentino di Gallura and Vermentino di Sardegna).

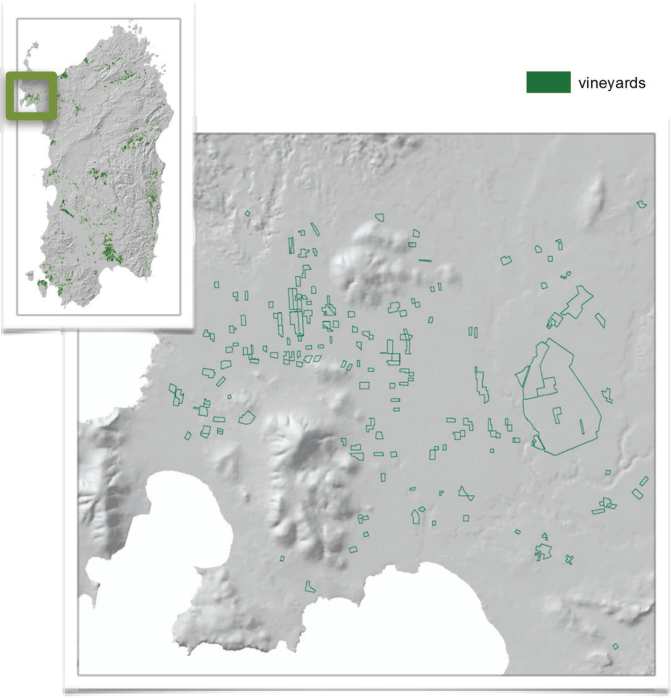
The grapevine is still among the most influential voices in the formation of regional gross production, according to data provided by ISTAT[20], the value of the local wine production, in 2010, slightly less than 44 million euro. Of these, roughly 31 million are attributable to the wine and 5 million from the sale of table grapes. In percentage terms, the wine industry is worth about

[19] https://www.regione.sardegna.it/j/v/2582?s=1&v=9&c=4939

[20] http://www.istat.it/en/

3% of the overall regional agricultural production, 7% of the value of output comes from crops, while affecting the domestic production to 3%.

The production of grapes is more than thousand quintals seasonal 600/700 (in 2014 -746 ml/ha); In recent years Sardinia has been a wine production in sharp contrast to the rest of the country, after years of net losses and thanks to a boom in the production of red wines wine production has grown by 17% compared to 2013 and is the 40% above the historical average.



Viticulture distribution area of reference, as a limited extension, has viticultural models differentiated.

In the area of Alghero, the plains and particularly fertile land, the widespread presence of irrigation and a company size well above the regional average, favored the introduction of a specialized wine-growing model where the vines are trained in the counter-pruned cordon or Guyot, depending on the variety or the lens wine.

Figure 19 - The DOC area of Alghero

The grapes are normally about 1 meter above the ground, are high and suitable for the production of wine is ready to drink or sparkling wines, both structured red wines.

Figure 20 - The wine predominant model of grapes in Alghero

The most cultivated variety is Vermentino, followed by the Cannonau. There are also international varieties such as Chardonnay, Cabernet sauvignon, and Merlot. Very few are the old vineyards still bred to tree, present mainly in the area of Maristella.

In the figure 20 it's easy recognise a counter-pruned cordon during the period of dormancy (pictured left) and an espalier (pictured right) is characterised by large and lush foliage.

With more than 1,000 hectares in cultivation, Alghero is the municipality that has a greater dissemination of the culture of the vine in the island.

In this countryside there is also the winery of Sella and Mosca, one of the largest contiguous vineyard in Italy this 1,600-acre property with more than 1,200 acres of vines, over 500 hectares, is one of the largest wine estates in Europe. In figure 21 from the Sella and Mosca website and the description of Torbato grape and wine.

Figure 21 - The Torbato grape and wine

The vineyards of Sorso Sennori

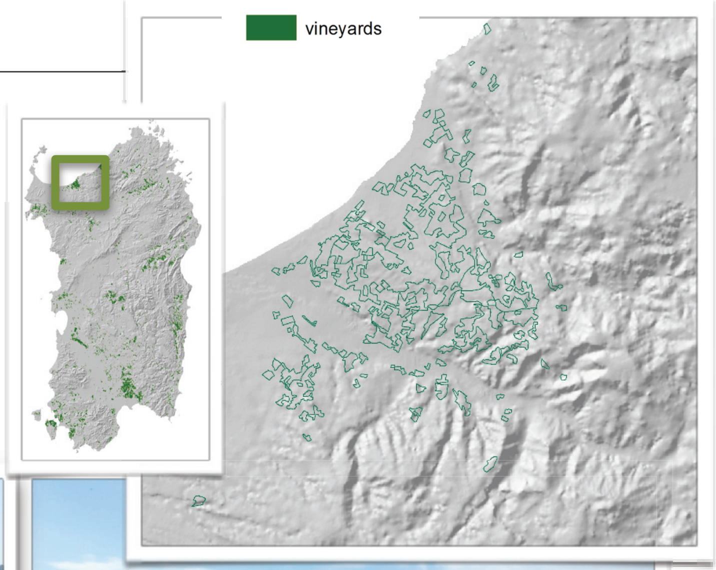


Figure 22 - The wine predominant model of grapes in Sorso and Sennori

The area of Sorso - Sennori, characterised in the past by a free wine-growing foot, thanks to the presence of plants located on extremely sandy soil proximal to the coast, today is localized mainly in the hinterland, where the soils have a clayey texture, sometimes traces of limestone. In these contexts, thanks to higher fertilitized, in the seventies were several vineyards were settled in the tent, which guaranteed much higher productivity of the vineyards on the sand. Currently new plants are set against espaliers, mainly operated with mixed pruning, where the Cannonau, increasingly widespread in facility, ensures extremely variable quality productions between 60 and 90 quintals per hectare.

Vermentino, Monica, and, invariably, the Moscato, are the other varieties most cultivated in the district. As for the types of farming, 50% of the vineyards, with over 30 years, it is still bred to tree, while 47% of the vineyards, primarily new plants, are against espaliers. Only 3% of the vineyards are raised canopy, farming system that has been phased out, although in the past has contributed significantly to the characterisation of the distribution landscape Sorso-Sennori.

The vineyards of Sassari

Nurra of Sassari differs from the remaining areas for the mainly calcareous of areas for the cultivation of vines. Also in this area we are witnessing the simultaneous presence of old trees and new against espaliers, very similar to those carried out in the countryside of Sorso-Sennori.

A distinctive feature is the spread, in this range, the Cagnulari varieties, grown in purity in the new systems of counter or with Pascale di Cagliari and Cannonau in old trees. It is also widespread cultivation of Vermentino. For cultural characteristics of the two varieties, against espaliers are almost exclusively held for long pruning methods. Nurra of Sassari in the vineyards sapling are still prevalent sapling than spurred cordon espalier (on the right).

Figure 23 - The wine predominant model of grapes in Sassari

Figure 24 - The drop irrigation system in the spurred cordon espalier vineyard

Materials and methods

Objective I: temperature trends from 1951 to 2010 in Sardinia

The first objective, as reported in the Objectives paragraph, is to analyse historical daily temperature data **to determine if there is a trend of temperature increase from 1951 to 2010 in Sardinia**. I conducted a specific case studies in Nurra, region of the north-western part of Sardinia.

This is achieved through the analysis of historical meteorological and agro-meteorological datasets and for a reference period of at least 60 years, considering for example time series that start from 1951. Several factors were found to be of fundamental importance when making relevant considerations in the context of eventually climate changes. These factors ranged from the quality of dataset information, the lack of gaps in the historical dataset, the length of the time series, the list of the people who, over the decades, collect the measurement registered by the mechanical sensors, or the landscape changes due to a developing urbanised area around a general reference meteorological station.

The acquisition of meteorological data set and the quality of data to be processed appear fundamental. Therefore, the weather data of all the stations of all the databases, useful for the analysis of the reference meteorological values and the calculation of all the bioclimatic indices and the thermal time indicators necessary for the development of this thesis were acquired. The dataset used is described below.

The historical network of Hydrographic Institute

The oldest data of the hydrographic service of Sardinia are from 1922. During the decades there was a significant variability in the number of meteorological mechanical huts available in the area. We have about 300 mechanical meteorological stations huts scattered in the region and read manually by operators every week. The mechanical huts typically contain a thermometer maximum and minimum, a thermograph, a pluviograph.

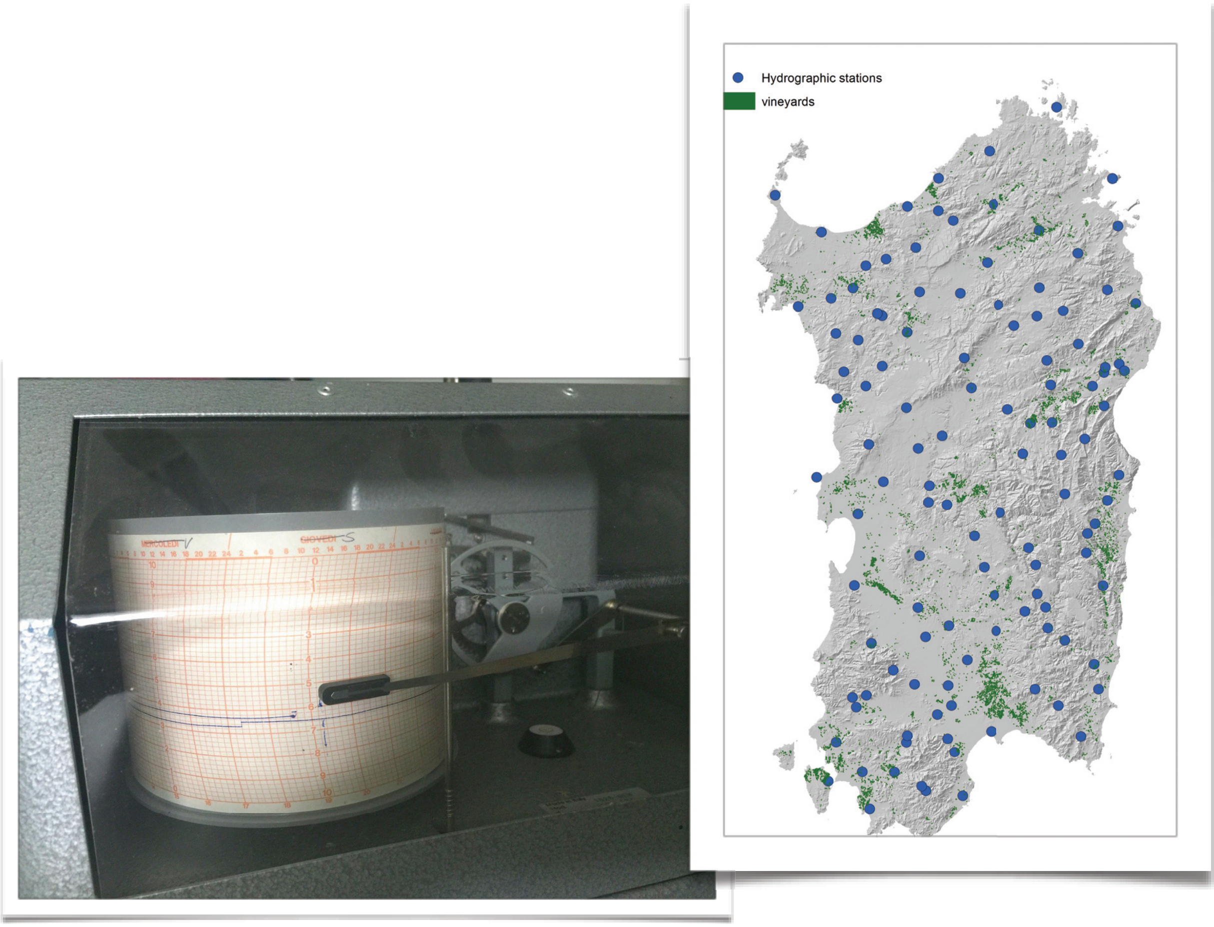


Figure 25 - The Hydrographic network and a dismissed rainfall recorder (pluviograph)

The meteorological station network is gradually replacing mechanical huts with automatic ones, for purposes of National Civil Protection. The hydro-meteorological rain gauge network in real time, which will gradually replace the one made up of so-called traditional stations, has been operational since 2007 and consists of 92 measuring stations (Region Sardegna, 2013) and 8 bridges signal repeaters which communicate with Central located in Cagliari Acquisition through radio devices operating in UHF mode powered by photovoltaic panels.

The Arpas meteorological network

The Environmental Regional Agency of Sardinia, equals Arpas, works to promote sustainable development and to protect and improve the quality of natural and man-made ecosystems. The Arpas has a network of distributed SIAP stations across Sardinia. The system has been operational since 1995, and this is designed to collect and process data arriving in real time from their weather stations weather detection. On the island, there are currently about 60 Arpas automated stations that can be divided into agro-meteorological stations and agro-synoptics, which mainly differ in the number and type of meteorological parameters that can be measured. Every station has a Datalogger, to record the data.

Figure 26 - A SIAP Datalogger

The agro-meteorological stations have sensors capable of measuring the following data:

- air temperature
- surface temperature
- ground temperature -10 and -50 cm
- precipitation
- relative humidity
- wind speed at 2 m
- wind speed at 10 m
- global radiation
- diffuse radiation
- leaf wetness

The agro-synoptic stations have sensors to measure:

- air temperature
- precipitation
- relative humidity
- wind speed at 2 m
- leaf wetness
- sunshine duration

The collected data enters in the Database of the of Arpas in Sassari. Such data logger are connected via GSM mobile phone network to the front-end present at the Department Data Processing Center Climate Weather Arpas where they are checked and entered into the database. When the network was born in 1995, the GSM connection allowing faster data acquisition. To ensure the arrival of the data at C.E.D and their verification, the stations, as well as being provided with telephone connection, have removable memories that are periodically collected and transported to the Regional Centre for reading and subsequent verification of the data already included in the database; they also provide a security system for the data storage, where they can not transmit them to the front end. This network is being sold in anticipation of a new network of automated stations that will take over the coming years.

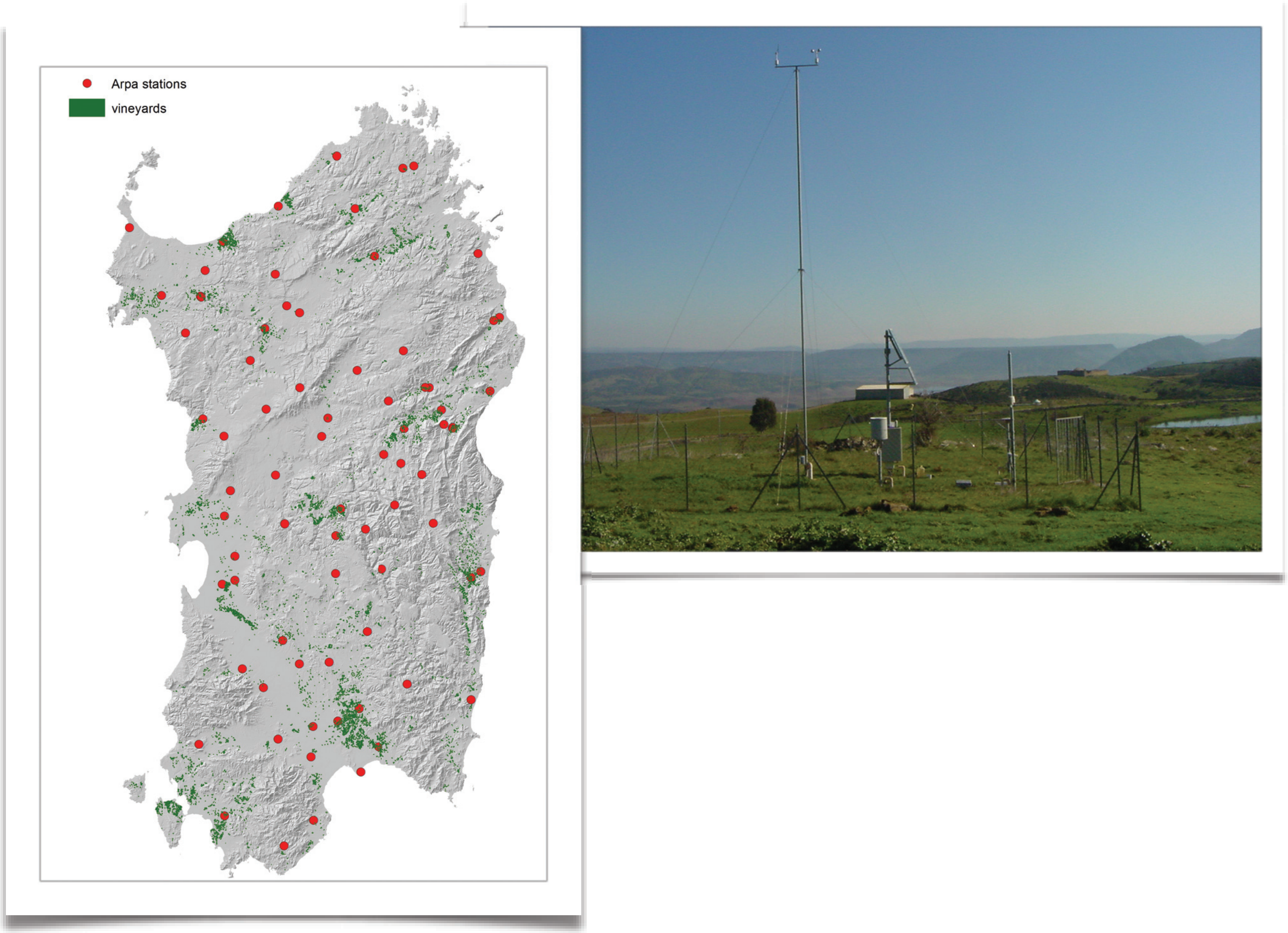


Figure 27 - Arpas network and Siurgus Donigala (CA) meteorological station

In R, statistical analyzes of long-term data series were conducted. In particular, some statistical analysis procedures have been applied, including Strucchange (Bai and Perron, 2003).

Objective II: understand the impact of this potential climate change on viticulture

The second objective of the thesis is to understand the impact of this potential climate change on viticulture through the application of NHH. So, in addition to the data used to define the first target, we calculated some thermal indexs on hourly data rather than on daily basis.

Recent studies show that models using NHH perform better than Degree-Day models (GDD), for all statistical indices tested and the depended variables (Cola *et. al.*, 2012). Experimenting with different application methods of analysis, testing different thresholds. Furthermore the GDD assumes a linear relationship between plant development and all temperatures above the threshold value for biological activity, (Mechilia and Carrol, 1989), and this simplicity leads to inaccuracies in the GDD predictions (Barger, 1969).

The Normal Heat Hours

The approach to NHH is pushed to the detail zone and normalizes the temperatures by means of the following response curve (Wang and Engel, 1998) that represents the effectiveness of the temperature for phenology some plants (Boyer, 1973).

$$NHH = (2\ (Th - Tcmin)\ \alpha)\ (TOPT - Tcmin)\ \alpha) - (Th - Tcmin)\ 2\alpha) / (TOPT-Tcmin)\ 2\alpha$$

Where:

Th = time temperature under review

$\alpha = \ln (2 \ln ((Tcmax - Tcmin) / (TOPT - Tcmin)))$

Tcmin - Minimum temperature Cardinal - lower limit below which the temperatures are not effective for the reporting process;

TOPT - Optimum temperature for the process

Tcmax - Maximum temperature Cardinal - the upper limit beyond which the temperatures are not effective for the reporting process.

The agro-meteorologist does not use temperatures below a certain threshold temperature values, because below these values it has an enzymatic slowdown that reduces cell growth and is defined as *cardinal minimum temperature of development*.

Stress from high temperatures which leads instead to the closing of the stomata is called *Cardinal maximum temperature of development*.

The *Growth optimum temperature* is the temperature at which it is believed that at the various phenological phases plants can best express their potential for development.

The methodology is published here for the first time and takes advantage of datasets already in use at ARPAS which have never been previously presented in peer-reviewed scientific publications.

Specifically, the cardinal and optimal temperatures for the development of grape have been obtained in the activities of the Italian Phenological Network (Mariani *et al.,* 2007, Mariani *et al*., 2011; Cola *et al*., 2012, Mariani *et al*., 2013) and have been used to calibrate simply local phenological models since 2008. We use 8 °C and 10 °C as Minimum temperature Cardinal, 22 °C like optimal temperature for grapes during the spring and we use 26 °C like optimal temperature for grapes during the summer, we use 35 °C as Cardinal maximum temperature of development. Similar methods have been successfully applied to other species, e.g. *Pistacia vera*, for example with 14 °C, 16 °C, 32 °C (Rahemi *et al*., 2009)

The High Heat Hours

Evaluating the heat overflow is very important for assessing the thermal stress conditions.

This calculation can not be done with heat time indicators such as GDD since they considers only maximum and minimum critical temperature thresholds, leaving out the optimal temperatures.

The Hight Heat Hours thermal excess can be calculated with an index derived from the same NHH calculation.

For each hour when measured T °C is greater than optimal temperature, HHHs are equivalent to the difference between 1 and NHH (where 1 is the NHH value when the measured hourly temperature corresponds to the optimal temperature):

T °C hourly > T°C opt

$$HHH = 1 - NHH$$

Methodology adopted for the calculation of NHH

The recent classification took by Fitchett *et al*. (2015) and Zhao *et al*. (2013) subdivides mathematical models of plant phenological events into three categories:

- statistical (empirical) models;
- mechanistic models which explore the biological processes that static models ignore, in the attempt to replicate the cause-effect relationships between environmental changes and the onset of phenological events, (Zhao *et al*., 2013);
- theoretical models, which are discussed in detail by (Zhao *et a*l. 2013).

The methodology in this study could be classified as a semi empirical approach. Half empirical and half mechanistic.

The NHH model is mechanistic as it refers to the algorithm's curve for parameterizing the grapes through the cardinal thresholds. It is obvious that there is still a dose of empiricism in this matter: a pure mechanicism would go down to the level of hormone-related processes that guide the phenological course and its rhythm (Kurth, 1994; Larcher, 1995, Traini, 2007).

NHH 1971-2000

For calculating the average climatic year on dataset 1971-2000, 31-day moving windows were used, centred on each day; for example, a window starting from January 3 up to February 2 was used to calculate the climatic average of January 18. This has two effects: on the one hand, it significantly reduces the random error of the measurement because the impact becomes much lower and decreases in the order of magnitude; on the other hand, short-term weather variability is filtered out, since, for example, a one-day thermal drop of 10 degrees would still have a significant weight if averaged over 31 days, but an almost negligible weight when averaged over 930 days (that is, over the days included in the moving window using all 30 years of data). In other words, a single episode in the context of 31 values weights a lot, but it weights a lot less in the context of 930 values. Then applying moving windows means reducing the weight of transients and possible measurements errors, therefore highlighting climate change variability.

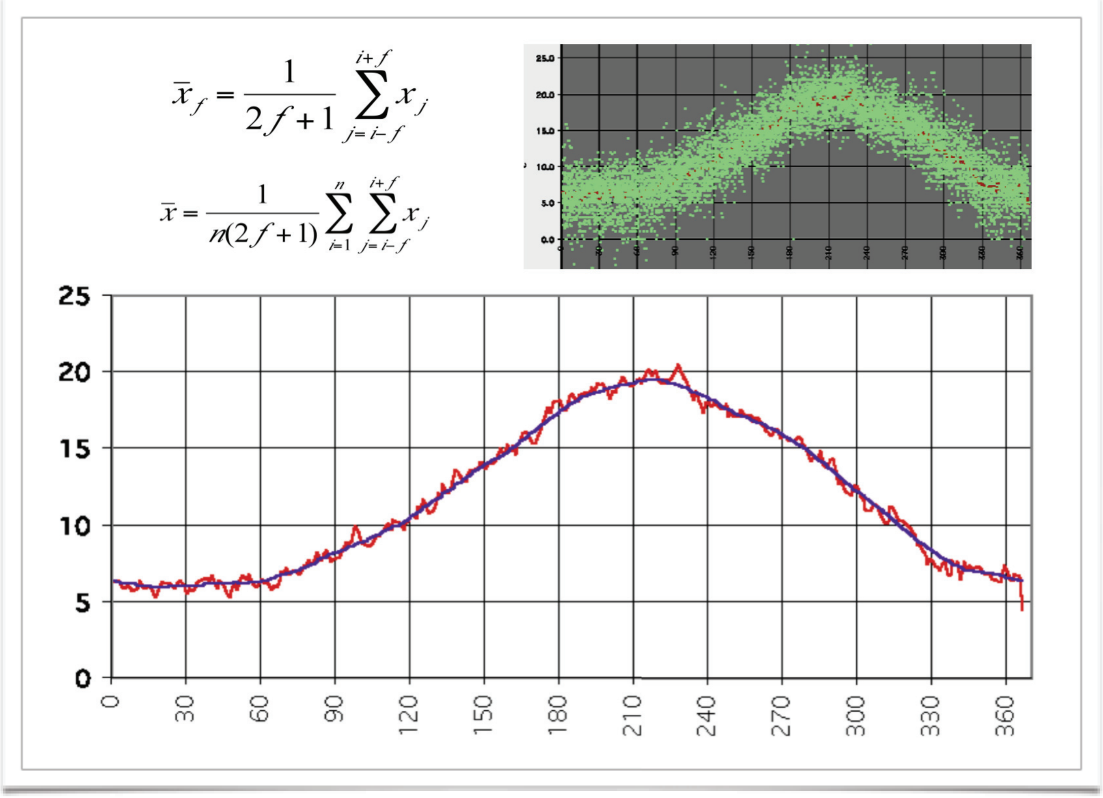


Figure 28 - Sassari sample for the average climatic year on dataset 1971-2000

Left-top formula of the moving average. to the left bottom the formula for the climatic average for the thirty years of reference 1971-2000. Right above the daily values of the thirty-year minimum daily temperature reference, in the lower right, the type chart for a single station (example Sassari), where we have the arithmetic mean in blue, the blue, the climatological average, much more homogeneous. The chart compares individual daily values, the classic thirty-year arithmetic average, the climatological average with the mobile window for the Sassari station

With the 365 days of the average climatic year 1971-2000 we calculate the hourly NHH for each day, so we obtained the climatology of the NHH: in Appendix 1 at the end of the thesis the R code used to calculate the NHH with different thresholds. The hourly temperatures are obtained from average climatic year 1971-2000 maximum and minimum temperatures using the Parton and Logan's algorithm of 1981 implemented in the R function "temp_hr".

We calculated NHH 1971-200 for 73 weather station.

NHH 1995-2015

In parallel, the NHHs were also calculated for the period 1995-2015 using the Arpas network established in 1995, which, as described, has hourly data and 144 daily measurements. The WMO explicitly rules out how to use twenty years of weather data for climatological assessments. However, the calculation of NHHs from 1995 to 2015 appears crucial to calibrate the phenological data obtained from the Sella and Mosca wine-growing company for that same reference period. In practice, with the 2005 phenological data, NHH can be calculated by comparing them with the 1971-2000 reference climatic value to assess any anomalies and understand the reasons.

Sella and Mosca phenological dataset

The Sella and Mosca phenological dataset from 2001 to 2013, observed by agronomist on the cultivars Cannonau, Nasco, Torbato and Vermentino is acquired for.
During 2015, the dataset was extended with supply datas from 1992 to 2016 on Cannonau and Cabernet sauvignon; in integration of the dataset of weather data Arpas - Hydrographic Institute, the data of the weather station of Alghero Airport were acquired.

Other phenological datasets

For some years of the decade 2000-2010, the phenological data on the cultivars Cannonau, Vermentino, Chardonnay, Cabernet sauvignon Cagnulari, Carignano and Monica recorded by Winery cellar of Santa Maria la Palma (Alghero) have been used for,. These vineyards are very close to the Sella and Mosca ones and this is useful to compare the quality of the dataset, especially in critical years, like 2004.

At the same time, I made directly, from 2002 to 2012, weekly phenological controls on 5 hectares of vineyards on Cannonau, Vermentino, Cabernet sauvignon, Chardonnay in one of the vineyards of the Winery cellar of Santa Maria la Palma

Objective III: extend the result from single points to larger areas

The third objective is to **extend the level of the results I and II from single points to larger areas, in order to generate maps of the region of Sardinia** by applying a suitable geo-statistical methodology and calculations and using the Geographic Information Systems (GIS). The maps of meteorological data (i.e. temperatures, rainfalls) and agro-meteorological indices could enable us to understand how indices varied across the territory. To accomplish this goal, it will be essential to increase the current resolution of the maps and get an appropriate resolution to be able to make local evaluations that take into account microclimate variability.

Geostatistical technics

The World Meteorological Organization, WMO, in 1967 has enshrined as "climatology" means a reference period of at least thirty years. To transform a single point weather data on a map, it is necessary for a geostatistical procedure. The temperatures, in fact, are adequately mapped and also the temperatures for long periods of reference, can be spatialized to obtain a maximum cumulative result (Campbell, 2013).

Calculations are made by averages of daily data of 1971-2000 climatological values.

In the network, there are available rain gauges every about 117 square kilometers and-and thermometers every about 348 square kilometers. Not all stations have both rain gauge that the thermometer or the maximum and minimum thermometer.

It was realized the spatial interpolation of climate data: T ° C min, T ° C max, average rainfall.

For the temperatures and the derived indexes, the method of multiple linear regression was used, while Kriging regression was used for precipitation.

For the multiple linear regression the parameters were considered latitudes, height above sea level of the station, the distance from the sea and the height from the bottom valley. In order to weigh the various contributions due to these variables during the different periods of the year, a specific analysis is performed through a stepwise regression statistical procedure that selects factors that have a significant relationship with the magnitude, comparing different complexity models and using the AIC[21] criterion to find the best model.

To execute the stepwise regression, the R stepAIC command is used, after which it will be recalculated manually to verify the congruity of the results. Model response from experimental

[21] https://stat.ethz.ch/R-manual/R-devel/library/MASS/html/stepAIC.html

measurements (model residuals) while others focus the correlation between model estimates and measurements (Bellocchi *et al*., 2002).

In practice, the procedure first puts all the factors down, then gradually removes one by one, by statistically comparing what the combination that determines the minor error and the greater statistical significance.

With regression Kriging the procedure consists of two different phases: the first consists of multiple linear regression, the second is the interpolation of the remaining residue with the methodology of the ordinary Kriging.

The procedure with the R list and some of the commented statistical tests are in Appendix 2.

Statistical tests permit to verifying the quality of the results.

The agroclimatic and bioclimatic index

To assess the agro-climatic requirements of the vine were introduced numerous bioclimatic indices suitable to define the vocation of a vine-growing territory, to differentiate the various wine-growing areas according to the desired objective.

The following bioclimatic indexes were then calculated:

Water deficit

The climatic water deficit, for the April-September period, is calculated as the difference between precipitation and evapotranspiration of reference and is an indicator of the degree of dryness of the territory. This index provides valuable information on the conditions of greater or lesser water stress which may be submitted a crop during the harvest cycle. This factor is of some importance to become decisive for the production and quality results in areas with no irrigation facilities. The reference evapotranspiration is calculated with the Hargreaves-Samani method, based on the air temperature.

PPAR

The analysis of the Potential Photosynthetically Active Radiation, (PPAR), available for the photosynthetic process, for the April-September period, was conducted with an appropriate model can calculate, from a digital elevation model (DEM), the photosynthetically active radiation potential in the period from April to September, which is that which is made available in the absence cloud cover. This processing allows you to evaluate and differentiate between different territories in the hypothesis that the cloud cover was apportioned evenly.

Huglin Index

The *Huglin index of heat* or the *Huglin index*, which calculates the temperature sum above the temperature threshold of 10 °C from April to September. Daily mean and maximum temperature s are used in the calculation. (Campbell, 2013).

Each grape variety therefore needs a certain amount of heat in order to be cultivated in the long term in an area with success. The calculated thermal sums, the basis of which are data from weather stations, differ from the actual values in the wine cellars due to too low sums.

This Index is also called *Eliotermic* because it improves the validity of using the Growing degree days. The index also considers the length of the day period, through a multiplier coefficient (K) between 40 ° and 50 ° latitude ranging from 1.02 to 1.05. The formula highlights the role of the maximum temperature. This is why it is more widely used than the Winkler Index, which is a simple thermal sum, and is more suitable for describing areas with hills and daily excursions in temperature. It is an improvement of the simple thermal sum that only considers the cumulated mean temperature, where Tmed is the average daily temperature (°C), Tmax is the maximum daily temperature (°C), and K is a multiplier coefficient.

Type of wines	IH
Sparkling wines	1200-1500
Light table wines	1300-1500
Distillation wines	1500-2000
Top Table Wines	1500-2000
Very alcoholic or dessert	2000-2800
Early table grapes	1200-1500
Early table grapes	1200-1500
Table grapes I and II era	1500-1750
Table grapes III and IV era	1750-2000
Late table grapes	2000-2800
Grapes to dry	2000-2800

$$IH = \sum_{01/04}^{30/09} \frac{(T_{med} - 10) + (T_{max} - 10)}{2} K$$

Figure 29 - Huglin index ranges and formula

Fregoni Index (simplified)

The Fregoni Index (Fregoni and Pezzuto, 2000; Fregoni, 2003) is an index that is based on the sum of the thermal excursions during the last month of ripening before harvesting in which the sugars, anthocyanins and aromatic components of the grape juice are synthesised.

Tmax is the maximum daily temperature (°C), Tmin is the minimum daily temperature (°C) and h is the number of hours per day with temperatures below 10 °C for the month of September.

$$FI = \sum (T\max_i - T\min_i).(n°dd < 10°C)$$

Figure 30 - Fregoni index (simplified) formula

Objective IV: analyse a range of scenarios on climatic changes

The fourth objective is **to analyse**, applying projected climate change, **a range of scenarios to develop an understanding of what may happen in 2050 for the wine sector.** This will develop further understanding of the likely impact on the viticultural landscape, where the temperature increase may require the migration of the vineyards from the coastal areas to the hills. The application of the scenarios would allow assessment of the state of viticulture 1951-2050: from 1951 to 2010 with real data, and from 2010 to 2050 with the simulations of climate and phenological scenarios. Furthermore, being able to work at a sufficiently detailed resolution to assess the local scale, you get the evaluation of "modification" of rural vineyards landscapes about possible climate change testing the calibrated phenological models, developed in this work by a real dataset, on the scenarios 2010-2050.

The coordinates used are expressed in latitude and longitude in the WGS84 geographic system.

Among the many models reported, the ones implemented by two of the world's most prestigious research centers (and even more reliable) have been chosen: NASA's Goddard Institute for Space Studies (GISS), the US Space Agency, and the 'Hadley Center of the UK Meteorological Office, having completed the internship at Reading University and having participated in the Agriclass research project using the Met Office methodology (Lukac *et al.*, 2016).

World Climate Data

WorldClim (World Climate Data) is one of the most important global portals that allows worldwide climate data download. Data resolution varies from a set of variable resolution mapping layers: WorldClim Version 2 has average monthly climatic data for the minimum, mean and maximum temperatures and precipitation for WMO 1970-2000 climatology. The datasets for different resolutions are from 30 seconds (~ 1 km^2) to 10 minutes (~ 340 km^2). In total, the database, continuously updated, consists of rainfall recordings of more than 50,000 stations. Available data are climate projections derived from General Circulation Models (GCMs) for different levels of RCP concentrations (Hijmans *et al.*, 2005). The map layers interpolated with WorldClim are processed using some databases such as those by Global Historical Climatology Network (GHCN), FAO, WMO, International Center for Tropical Agriculture (CIAT) (Cavagnuolo, 2015).

The model was just used in Sardinia also from Motroni and Canu for a case study of Sorradile in Sardinia and for some elaboration on the bioclimatic map of Sardinia, just reported in figure 15 (Motroni *et al*., 2015; Canu *et al*., 2015).

The GISS Atmosphere-Ocean Model

3D Model[22] on a grid of coordinates of latitude and longitude notes. The model (Russell *et al*. 2013) requires input of two types of data, specific parameters and variables (predictors), and produces two types of output, climatic diagnosis and prognostic variables. The input parameters for which it has been implemented are physical constants (earth's orbit, atmospheric data, topography, ocean mass distribution, prevailing vegetation, and other apparently secondary factors), but which overall evolve the system. Prognostic variables related to time include mass flows, horizontal velocity, heat, water vapor, saline content, sub-superficial mass.

Hadley Center model, UK

The model developed by the Hadley Center consists of two types of mathematical equations that are solved to make long-term scenarios. The model's main engine solves equations describing the predictive atmosphere motions of the atmosphere, and natural processes that change the temperature and the atmospheric humidity are also analyzed and are attributable to clouds and precipitation and the influence of the same on the scenario being analyzed, which can be described as a dynamic analysis loop.

Figure 31 - The new UKMO building[23] in Exeter, UK

[22] http://aom.giss.nasa.gov/

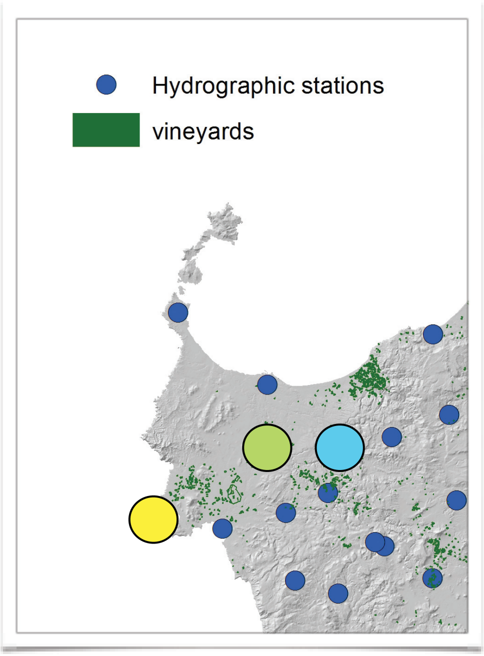
[23] https://goo.gl/images/M71QGf

Results

Objective I: temperature increase from 1951 to 2010 in Sardinia

It was particularly long and complex to analyse all data available dataset. To highlight a possible trend of temperature growth, it was not important to work as much as on a large number of weather stations, as well as to identify stations that during the 60 years that were the subject of analysis showed:

- continuity in data transmission as much as possible; constantly subject to ordinary and extraordinary maintenance (replacement of sensors, spare parts);
- continuity in the alternation of station officers-detectors that would guarantee accuracy in constant measurements over the decades;
- any type of modification of the surrounding landscape (eg, buildings of palaces that could somehow affect the measurements).



Data from 1951 to 2010 have been drawn up for the stations of Nurra with a continuity of weather data: St. Giovanni Coghinas for Sorso, Ottava, (1958-2013), for Sassari and Capocaccia for Alghero. The first station operated by the Hydrographic Service of Sardinia, the second is managed by the Department of Agriculture, University of Sassari, the third by the *Italian Military Aeronautic*s. The most rappresentative station is San Giovanni Coghinas because of the quality of the recorded data set and the continuity of information during the years. The station officers-detectors were first the father and then the daughter.

Figure 32 - Ubication of main stations of the Hydrographic Institute dataset St. Giovanni Coghinas (azul), Ottava (green) and Capocaccia Station (yellow).

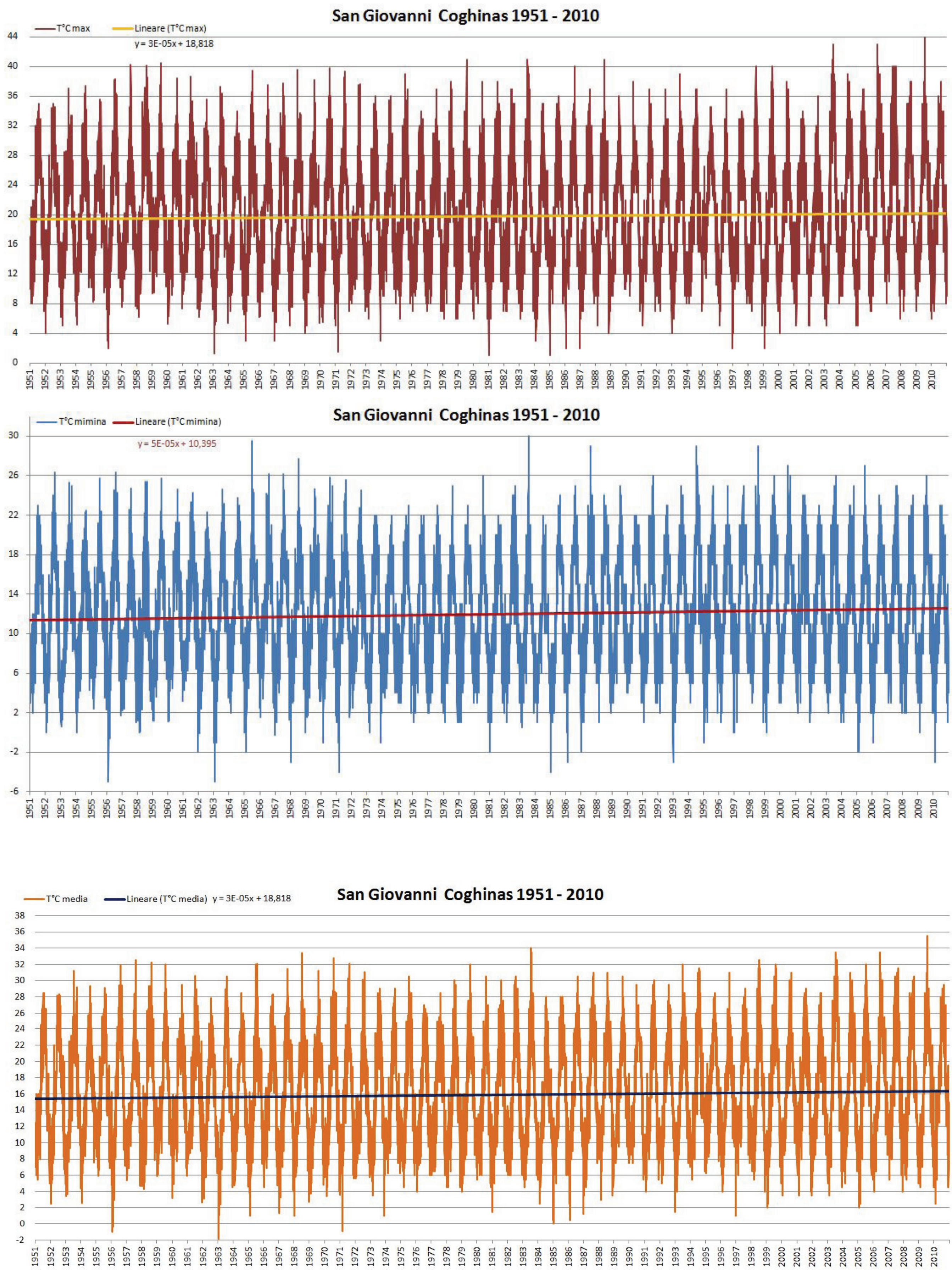


Figure 33 - Daily temperature trends of San Giovanni Coghinas station 1951-2010

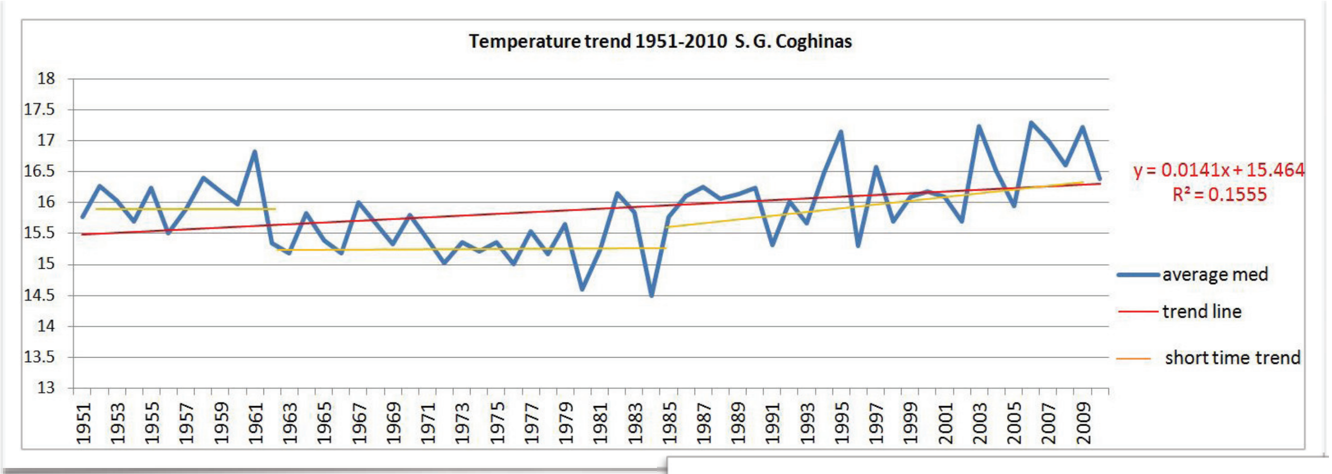
The trend of thermal increase of daily temperature is particularly evident between 1951-2010. The trend of thermal increase of the maximum and minimum is almost 2 °C. The line function expressing the trend of maximum temperature, is: y=3E-05x + 18,818. (Figure 33)

The average temperature increases by about 1.4 °C.

However, the daily data is affected by the seasonal cyclical variability.

To minimise this component and to better visualise the climate variation we have worked on the average annual temperature. in red in figure 34, at the top, it is represented the trend line.

In fact, the trend is not unique. It is separated into three sub units. they are reported in the yellow display lines. The strong by an Italian trend, shown in Figure 34 on the bottom right. The most important growth is from the 80s onwards.



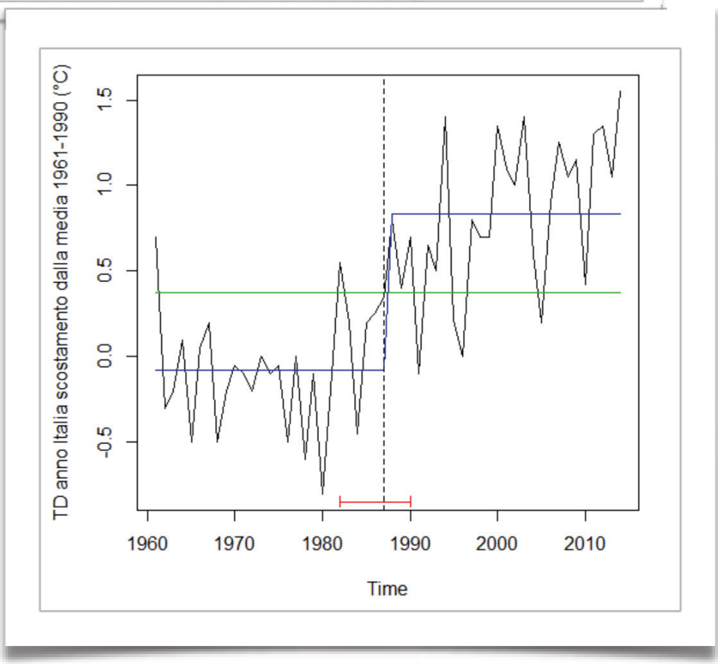


Figure 34 - Average annual temperatures of S. G. Coghinas and comparison with italian trend

Breakpoint analysis performed in R environment with the help of the Strucchange statistical procedure (Bai and Perron, 2003) is illustrated by the diagram in figure 34 on the right, which shows that with a probability of 99% a breakpoint occurred during the period between the 1982 and the 1990s cone highlighted in the horizontal red line diagram.

Breakpoint's most likely year of 1987 (vertical line dashed in the middle of the graphic) and following this event, the average temperatures in the Italian area ranged from 12.9 °C to 14.0 °C (blue line), while the average of the entire 1973-2016 series was 13.6 °C.

In climatological terms, breakpoint interpretable as a symptom of abrupt climatic change and corresponds to the event already highlighted at European level by various authors (Mariani *et al*., 2012; Reid *et al*., 2016) and which has its cause in a change abrupt in the regime of the great western corerns highlighted by the phase change of the North Atlantic Oscillation (NAO) index occurred in 1987 with the passage of the index itself to a very positive phase, which means increased increase of subtropical Atlantic air towards the nose area. The new established climate regime was then stabilised by the temperature rise of the Atlantic Ocean surface and the Atlantic Multidecadal oscillation Index passed from the negative stage to the positive phase in 1994 (Mariani and Zavatti, 2017).

Objective II: understand the impact of this potential climate change on viticulture

By the network of automatic stations, we can work on hourly data rather than on daily basis. Experimenting with different application methods of analysis, testing different thresholds, I conducted a specific case studies in Nurra, region of the north-western part of Sardinia.

NHH 1995-2015

As illustrated, the automatic network of Arpas stations is operating since 1994 with 144 recordings of thermal and rainfall hourly data. To have the highest data quality we have chosen 36 stations for the period 1994-2013, installed between 1994 and 1995, and calculate all the agrometeorological parameters. Most of them are important as extra analysis for the surrounded area, necessary to verify results of Objective III.

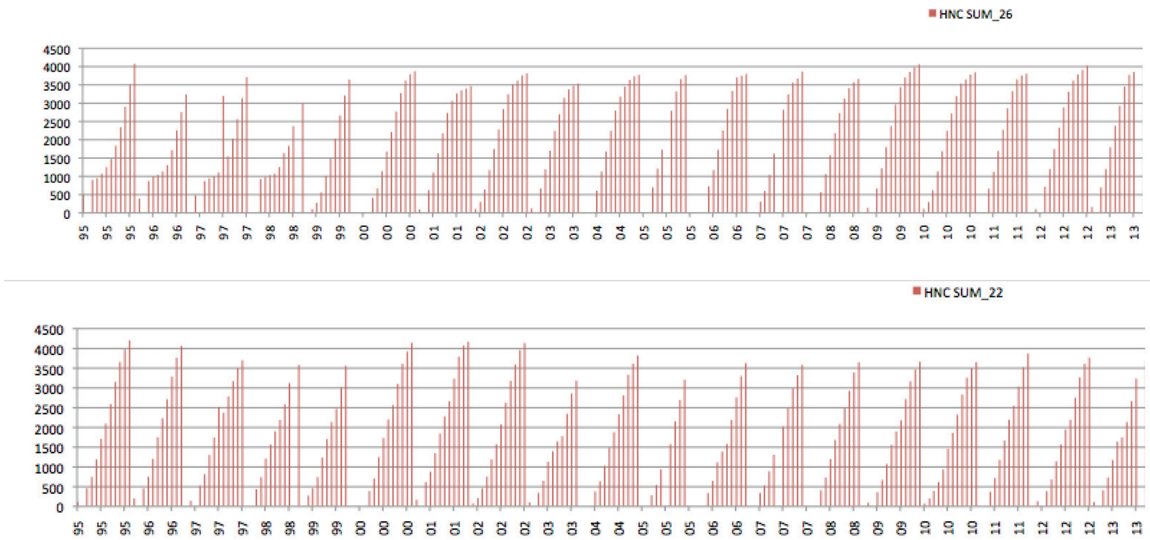


Figure 35 - NHH 1995 - 2013 for Olmedo station - September

In the table on the left are reported the stations chosen and used in the analyse with their UTM coordinates. At the same way of Objective I for Capo Caccia, Ottava, San Giovanni Coghinas, it was choosed Olmedo to represent Alghero, Sassari for Sassari Nurra and Sorso station for Sorso Sennori and verify the NHH cumulated calculated with hourly data.

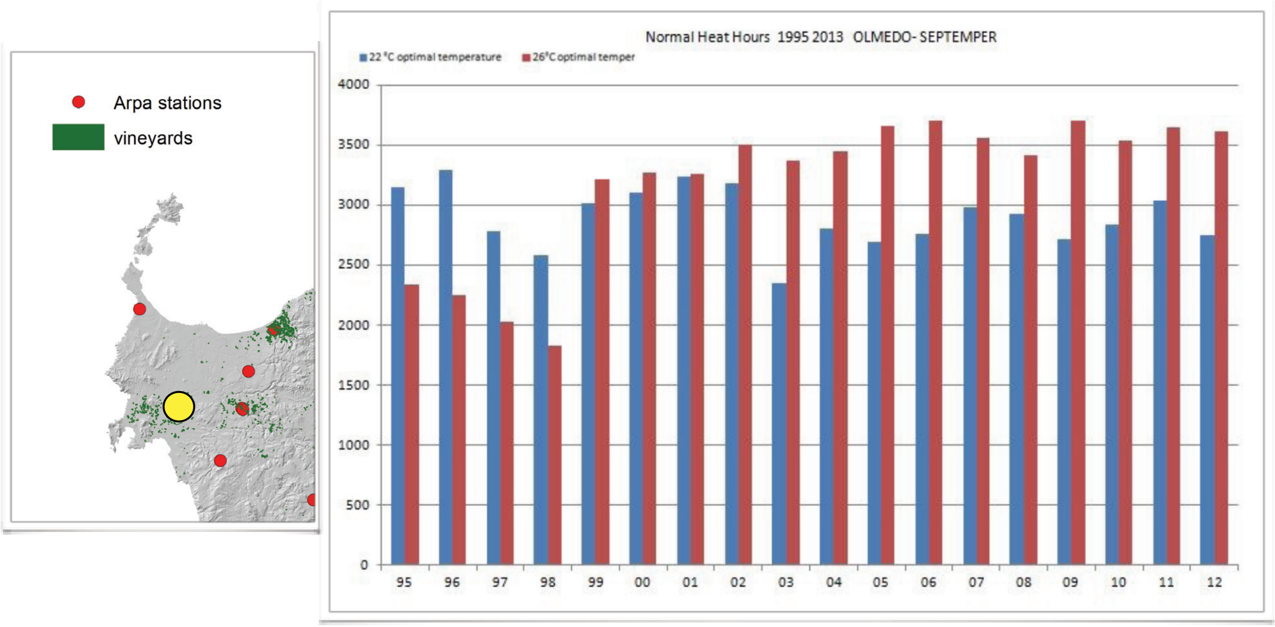


Figure 36 - Seasonal cumulate of NHH for Olmedo 1995-2013

The grape phenology of Alghero

The vineyards of Sella and Mosca are located in homogeneous areas of property and without any particular obstacles, buildings, windbreaks, so all phenological data acquired have been useful for the study. This does not happen very often by working with the phenological data.

Figure 37 describes the main vineyards used for the phenological dataset.

Position	Grape variety	Hectares	Number of plants
SOUTH	Cannonau	137.888	> 55000
SOUTH	Cannonau	2.3515	> 8000
WEST	Nasco	2.6021	> 6000
WEST	Sauvignon	0.6754	> 1700
NORTH	Torbato	5.4639	> 19000
	Vermentino	3.5195	> 14000

Figure 37 - The main vineyards studied

The Sella and Mosca phenological dataset was acquired at the beginning from 2001 to 2013 for the cultivars Cannonau, Nasco, Torbato and Vermentino. During the last year of the thesis it was extended from 1992 to 2016 with datas on Cannonau, Cabernet sauvignon and Vermentino also the dataset. The criterion for acquisition of the phenological data was consistent with the protocols used during the lasts years. The phenological data are converted to BBCH scale.

The average grape phenology time has been calculated for each cultivars of Sella and Mosca (Cannonau, Nasco, Torbato and Vermentino) using data about 2001-2013 years. Uniformity of seasonality has been tested using Freadman’s test, resulting statistically significant for each seasonal trend evaluated ($p < 0.01$), underling different distribution of BBCH phases 10, 65, 81, 89. Seasonal peak was establish using Edwards's test (for a harmonic curve - 6 months between peak and trough) and peak date are shown in figure 38 as day/month, (Edwards, 1961).
All p-value resulting from Edwards’s test where statistically significant ($p < 0.05$).

CULTIVARS	BBCH 10	65	81	89
Cannonau	April, 5th	May, 24rd	July 26th	September 23rd
Nasco	April, 8th	May, 24th	July 19th	September 15th
Torbato Freedman's test (for any deviation from a uniform incidence): V(N) = 0.923 P < 0.01	April, 10th	May, 28th	August 5th	October 2nd
Vermentino	April, 1st	May, 16th	July 26th	September 23rd

BBCH 65 STATISTIC DISTRIBUTION FOR THE DIFFERENT CULTIVARS

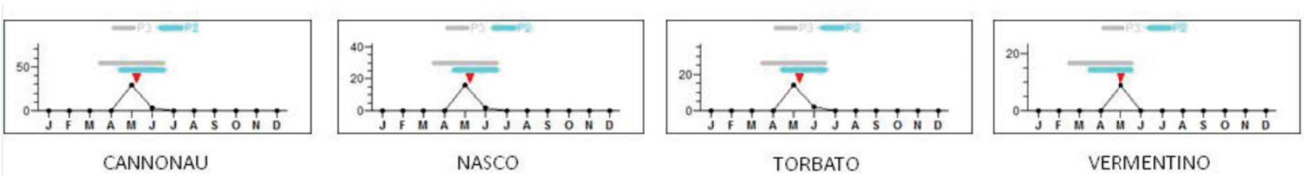


Figure 38 - Average grape phenology Sella and Mosca dataset 2001-2013 and statistic sample of Edward’s test for BBCH 65 phase.

Among the variety available, I chosed to work on cv Torbato because the oenological targets has remained constant over the years. This means that time of the harvest of the grapes depending on a a predefinite sugar content and acidity has not changed over time.

	Torbato															
	10	% data	NHH 22	NHH 26	65	% data	NHH 22	NHH 26	81	% data	NHH 22	NHH 26	89	% data	NHH 22	NHH 26
2001	8-Apr	75%	91	710	31-May	100%	174	1346	30-Jul	100%	120	2279	24-Sep	89%	176	3045
2002	16-Apr	80%	89	642	31-May	98%	165	1192	2-Aug	91%	165	2242	26-Sep	89%	166	3179
2004	10-Apr	76%	66	447	8-Jun	91%	167	1198	15-Aug	91%	136	2156	11-Oct	91%	178	3139
2006	5-Apr	58%	75	416	23-May	88%	139	932	2-Aug	91%	198	1781	28-Sep	90%	190	2759
2007	7-Apr	81%	87	616	22-May	65%	111	130791%	2-Aug	91%	152	2174	16-Oct	88%	144	3193
2008	10-Apr	81%	104	618	30-May	100%	168	1200	7-Aug	89%	103	2193	29-Sep	91%	147	2929
2009	12-Apr	82%	96	546	28-May	99%	112	1074	3-Aug	91%	125	2023	5-Oct	91%	184	2903
2010	15-Apr	34%	44	479	31-May	98%	179	935	6-Aug	81%	158	2019	8-Oct	91%	180	3014
2011	12-Apr	77%	113	487	28-May	100%	172	1178	3-Aug	91%	165	2361	4-Oct	88%	155	3192
2012	1-Apr	87%	80	489	28-May	97%	141	1175	3-Aug	89%	132	1952	2-Oct	91%	184	2848

Figure 39 - Mean grape annual cycle in cv Torbato and relatives NHH
(Sella and Mosca dataset 2001-2012)

Analysis matching phenological datas demonstrated for Torbato and Cannonau and Vermentino has highlighted a better match with the minimum critical temperature of 10 °C, most likely due to a question of climate adaptation of varieties compared to the mild climate of Sardinia. Cabernet sauvignon and Chardonnay fits better with 8 °C.

It was necessary an Excel Visual Visual Basic procedure that automates a series of tests and combinations to test optimal threshold temperatures. To capture the knowledge and preferences indices and test statistics are commonly used (e.g., of the user, weights may be used to establish the relative (Martorana and Bellocchi, 1999; Yang *et al*., 2000; Smith *et al*., 2014;). Some of them quantify determined by the user and may change for different users

c_MIN	C_MAX	Topt
7	35	22

				fvn(T)	NHH	BBCH C Sauvignov - Veg
1617	OLMEDO	09/03/2006 05:00	11.5	0.432	367.515	7.8
1618	OLMEDO	09/03/2006 06:00	11.2	0.403	367.918	7.8
1619	OLMEDO	09/03/2006 07:00	0	0.000	367.918	7.8
1620	OLMEDO	09/03/2006 08:00	0	0.000	367.918	7.8
1621	OLMEDO	09/03/2006 09:00	0	0.000	367.918	7.8
1622	OLMEDO	09/03/2006 10:00	0	0.000	367.918	7.8
1623	OLMEDO	09/03/2006 11:00	0	0.000	367.918	7.8
1624	OLMEDO	09/03/2006 12:00	16.1	0.805	368.723	7.8
1625	OLMEDO	09/03/2006 13:00	16.2	0.812	369.535	7.8
1626	OLMEDO	09/03/2006 14:00	16	0.799	370.334	7.9
1627	OLMEDO	09/03/2006 15:00	16.2	0.812	371.145	7.9
1628	OLMEDO	09/03/2006 16:00	15.2	0.745	371.890	8.0
1629	OLMEDO	09/03/2006 17:00	13.9	0.646	372.536	8.0
1630	OLMEDO	09/03/2006 18:00	12	0.479	373.015	8.0
1631	OLMEDO	09/03/2006 19:00	10.9	0.373	373.388	8.0
1632	OLMEDO	09/03/2006 20:00	11.3	0.412	373.801	8.0
1633	OLMEDO	09/03/2006 21:00	11.9	0.470	374.270	8.1
1634	OLMEDO	09/03/2006 22:00	11.8	0.460	374.731	8.1
1635	OLMEDO	09/03/2006 23:00	11.3	0.412	375.143	8.1
1636	OLMEDO	09/03/2006 23:59	11.6	0.441	375.584	8.1
1637	OLMEDO	10/03/2006 01:00	12.2	0.498	376.082	8.2
1638	OLMEDO	10/03/2006 02:00	12.7	0.543	376.625	8.2
1639	OLMEDO	10/03/2006 03:00	12.3	0.507	377.132	8.2
1640	OLMEDO	10/03/2006 04:00	11.9	0.470	377.601	8.2
1641	OLMEDO	10/03/2006 05:00	12	0.479	378.080	8.2
1642	OLMEDO	10/03/2006 06:00	11.6	0.441	378.522	8.3
1643	OLMEDO	10/03/2006 07:00	9.9	0.273	378.795	8.3
1644	OLMEDO	10/03/2006 08:00	10.5	0.334	379.128	8.3
1645	OLMEDO	10/03/2006 09:00	12	0.479	379.608	8.3

Figure 40 - Testing of thermal thresholds for NHH in relation to the phenology observed

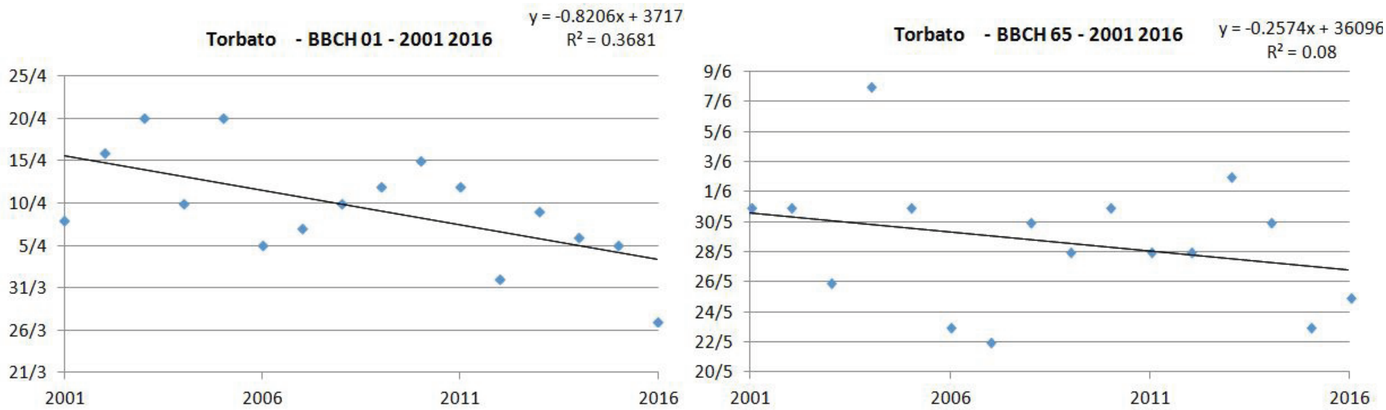
The phenological data from 2001 to 2012 for cultivars Torbato and Cannonau show a closed relationship between NHH and phenological phases with 22 °C for the spring phases and 26 °C for the summer phases.

For each single year, for each single phenological phase, the effects of temperature on phenology were evaluated for each variety of grape, the phenological delays, in red in Figure 39, and advances in green.

There may also be two weeks of phenological difference by comparing different years, with the same agronomic processing and winter pruning period.

For Torbato, the data in Figure 41, besides allowing to understand the relationship between NHH and phenological phases. The charts at the top of the figure, allow to appreciate the phenological advance from 2001 to 2016 for BBCH 01 and 65 phases.

Analysing the Torbato - BBCH 65 - by eliminating the 2004 data, which were abnormal because it was one of the warmer year of the century, the R^2 would be much higher. The BBCH 65 of 2004, due to the hot stress, was in fact very late and lowered the general trend.



variety	Grape bunching stage														
	'00	'01	'02	'03	'04	'05	'06	'07	'08	'09	'10	'11	'12	13	14	15
Cannonau			29/7	23/7	6/8	27/7	31/7	21/7	29/7	27/7	2/8	30/7	25/7	12/8	25/7	23/7
Cannonau		26/7	25/7	22/7	6/8	28/7	22/7	26/7	28/7	29/7	8/8	25/7	28/7	12/8	26/7	24/7
Nasco	12/7	17/7	19/7	16/7	30/7	25/7	20/7	19/7	30/7	19/7	22/7	16/7	20/7	29/7	20/7	18/7
C.Sauvignon	19/7	23/7	24/7	18/7	31/7	24/7	18/7	19/7	22/7	22/7	29/7	18/7	17/7	30/7	23/7	19/7
Torbato		30/7	2/8	29/7	15/8	5/8	2/8	2/8	7/8	3/8	6/8	3/8	3/8	16/8	1/8	1/8
Vermentino									26/7	26/7	30/7	26/7	28/7	4/8	24/7	20/7

date in the average of the surveys — late date — early date

Figure 41 - Phenological Analisys, bunching stage sample

Based on the above results, NHHs were calculated based on the following thresholds::

Minimum critical temperature 10 °C.

Maximum critical temperature 35 °C.

Optimum temperature 22 °C

called shortly **NHH 10, 22,35.**

Minimum critical temperature 10 °C.

Maximum critical temperature 35 °C.

Optimum temperature 26 °C.

called shortly **NHH 10, 26, 35**.

Minimum critical temperature 8 °C.

Maximum critical temperature 35 °C.

Optimum temperature 22 °C.

called shortly **NHH 8, 22, 35**.

Minimum critical temperature 8 °C.

Maximum critical temperature 35 °C.

Optimum temperature 26 °C.

called shortly **NHH 8, 26, 35**.

Minimum critical temperature 8 °C.

Maximum critical temperature 35 °C.

Optimum temperature 24 °C.

called shortly **NHH 8, 24, 35**.

Minimum critical temperature 10 °C.

Maximum critical temperature 35 °C.

Optimum temperature 24 °C.

called shortly **NHH 10, 24, 35**.

The NHHs with a minimum temperature threshold of 7.5 °C were first calculated, then eliminated for a better fitting of the 8 °C threshold.

NHH 1971-2000

The described method for obtaining climatology 1971-2000 NHH starting from the average climatological year to was applied for:

NHH 8,22,35	for the months of January, February and March
NHH 10,22,35	for the months of January, February and March
NHH 8,26,35	for the months from January to October
NHH 10,26,35	for the months from January to October
NHH 8, 24,35	for the months from January to October
NHH 10,24,35	for the months from January to October
NHH 8,22,35	for the months of January, February and March
NHH 10,22,35	for the months of January, February and March
NHH 8,26,35	for the months from January to October
NHH 10,26,35	for the months from January to October
NHH 8, 24,35	for the months from January to October
NHH 10,24,35	for the months from January to October

NHH calculation was performed for all available historical database, with over 232 useful stations. Observing datas a whole already on the output file of the developed R procedure, it was possible to understand which column belonged to the calculation (arrows in figure 42), whether it was a mountain or coastal station, from the delay with which the normal hot hours passed from 0 to numeric values; when the phenology starts.

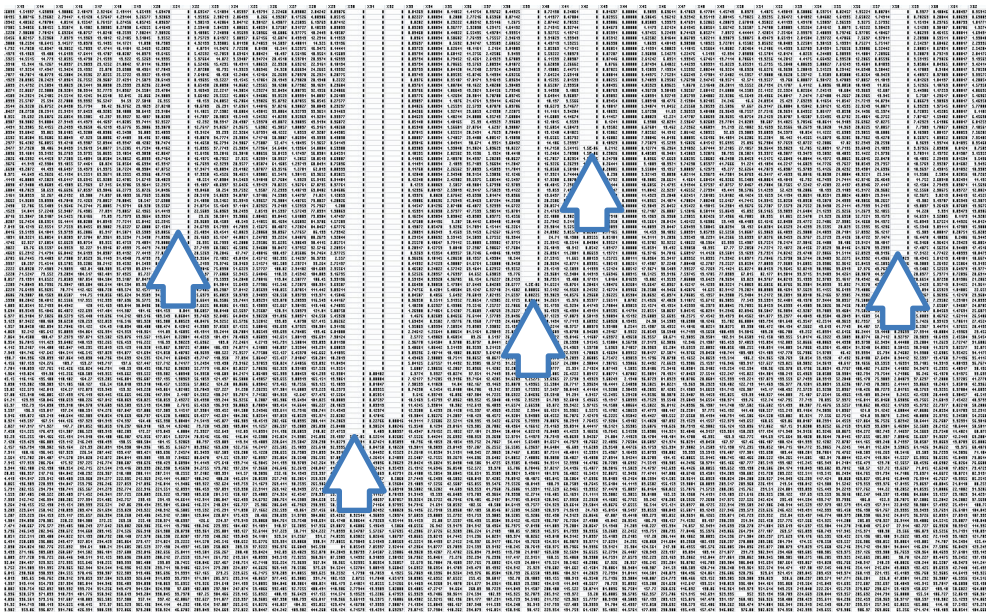


Figure 42 - Example of NHH output by R code

$\sum$ NHH

station	long	lat	quote	dist sea	gen 8 26 35	feb 8 26 35	mar 8 26 35	apr 8 26 35	mag 8 26 35	giu 8 26 35	lug 8 26 35	ago 8 26 35	set 8 26 35	ott 8 26 35
MACOMER	84654	401604	565.00	25240.00	9.77	26.71	94.34	236.45	594.62	1105.08	1675.36	2252.69	2739.08	3035.66
FONNI	91519	400704	992.00	32936.00	0.00	0.19	13.80	68.86	336.11	798.58	1417.34	2029.74	2429.70	2607.71
GENNA-SILANA (	93031	400934	1010.00	10915.00	0.00	0.00	6.81	42.32	240.32	640.64	1222.35	1785.32	2138.34	2289.84
DESULO	91351	400056	920.00	38911.00	6.07	15.70	63.79	153.59	427.44	877.75	1443.54	2003.77	2428.11	2651.48
COSSATZU (C.RA	91052	395638	860.00	43133.00	4.24	12.79	48.23	135.22	408.09	861.91	1439.18	2018.72	2441.18	2680.19
MEANASARDO	90425	395646	585.00	45385.00	14.21	31.67	93.12	223.89	579.80	1110.03	1730.22	2351.38	2862.52	3178.14
CAPO BELLAVIS	94251	395553	155.00	376.00	69.54	137.27	266.46	485.89	911.15	1507.40	2195.83	2886.31	3495.40	3943.79
ARZANA	93144	395505	674.00	13297.00	19.97	33.23	92.31	236.16	598.87	1150.48	1814.68	2475.38	2990.53	3309.63
LANUSEI	93219	395247	595.00	12288.00	28.98	57.11	134.19	283.56	643.98	1182.18	1820.75	2458.40	2981.77	3324.49
SANTA SOFIA	90760	395206	825.00	46769.00	1.64	5.31	32.44	98.25	341.12	766.56	1308.44	1843.76	2238.71	2440.86
JERZU F.C.	93045	394815	550.00	13712.00	36.45	75.21	177.67	368.94	775.80	1352.27	1999.07	2647.69	3192.03	3553.48
VILLANOVATULO	91251	394548	347.00	38841.00	20.59	46.09	115.25	248.26	591.67	1102.82	1704.23	2304.16	2791.08	3090.71
COL. PENALE SA	90845	394839	699.00	44999.00	4.45	12.49	50.18	139.34	420.12	880.53	1447.96	2016.49	2452.74	2690.92
NURRI F.C.	91349	394320	557.00	36640.00	7.61	21.33	76.48	189.54	505.37	1006.89	1600.97	2192.54	2667.71	2938.56
PERDASDEFOGU	92630	394057	599.00	18034.00	24.84	54.48	140.99	299.22	660.55	1185.64	1787.30	2389.98	2901.37	3245.04
CUGLIERI	83407	401127	484.00	8575.00	19.31	41.43	115.22	270.49	654.72	1200.30	1845.27	2493.02	3028.25	3381.64
BUSACHI	85350	400201	379	34396.00	21.88	49.99	131.39	291.27	674.80	1215.98	1831.75	2451.22	2982.48	3337.37
SANTA LUCIA	83702	395853	0	11639.00	68.14	140.47	280.73	504.98	942.23	1490.63	2094.77	2698.31	3243.15	3660.87
ALLAI	85157	395730	50	28691.00	53.54	125.52	279.54	529.01	966.98	1488.15	1981.23	2490.12	3009.71	3391.73
S.ANNA	83742	395005	12	6228.00	70.12	150.08	306.90	548.44	994.68	1567.10	2178.80	2793.17	3367.70	3820.97
S.GIUSTA	83635	395231	10	4960.00	70.84	146.97	299.43	540.57	990.89	1566.94	2190.81	2808.02	3374.24	3804.35
ALES	84920	394557	167	23836.00	32.27	79.65	192.57	376.07	772.65	1304.94	1868.71	2442.29	2932.92	3259.88
MOGORO	84647	394102	134	23207.00	37.28	85.42	201.67	418.68	875.39	1476.37	2139.67	2803.71	3387.06	3802.23
GUARDIAVECCHI	92415	411244	3	44.00	52.44	99.03	190.88	350.94	713.73	1259.28	1928.98	2613.15	3180.83	3574.48
LA MADDALENA	92403	411306	29	3204.00	76.57	149.68	285.97	510.42	939.67	1533.81	2230.07	2931.51	3546.28	4012.59
OLBIA	93032	405527	15	28.00	47.71	100.28	220.47	427.76	848.32	1438.66	2108.91	2777.90	3357.28	3756.86
TEMPIO	90618	405415	558	21185.00	3.26	9.08	47.36	151.74	480.45	990.08	1623.98	2253.51	2736.87	3009.89
S.GIOVANNI COG	84526	405301	210	3666.00	31.85	65.33	152.24	321.18	708.17	1254.11	1905.23	2559.09	3101.19	3467.96
MONTI	91935	404821	296	18897.00	13.37	32.10	96.78	223.18	537.03	1016.38	1588.44	2160.22	2631.28	2938.50
ZUIGHE	92204	404529	520	20585.00	5.51	16.26	55.32	140.13	416.59	865.90	1421.39	1972.93	2385.18	2602.14
SASSARI(SERRA	83731	403735	350	12658.00	28.34	63.12	154.94	324.12	717.34	1261.24	1900.94	2539.31	3067.67	3414.04
OTTAVA	82920	404635	70	4940.00	53.32	104.92	211.64	399.23	785.05	1317.03	1929.65	2545.14	3079.70	3466.51
OSCHIRI	90529	404328	205	33467.00	27.39	60.13	152.99	332.79	717.46	1245.32	1833.45	2417.50	2926.22	3249.09
ALA' DEI SARDI	91949	403905	663	32461.00	5.68	17.45	67.53	172.83	475.75	941.97	1495.16	2045.37	2475.48	2713.23
OZIERI	90017	403507	390	41570.00	17.93	43.50	127.94	287.93	655.90	1166.85	1727.32	2286.59	2776.35	3082.65
SOS CANALES (D	91826	403325	714	37460.00	0.83	2.92	27.94	94.99	342.25	768.26	1317.27	1858.09	2263.54	2468.19
ALGHERO	81741	403831	19	5199.00	58.06	114.37	221.58	406.88	797.57	1335.49	1958.90	2579.29	3113.85	3495.09
BIDIGHINZU	83912	403330	335	24618.00	27.65	62.29	161.70	335.54	727.02	1242.24	1809.37	2375.92	2849.54	3160.14
VILLANOVA MON	82827	403010	567	8497.00	2.51	7.40	44.52	151.07	482.18	988.20	1622.74	2253.06	2722.00	2981.09
S.LUCIA DI BONO	85034	402525	360	34078.00	18.06	43.62	120.98	268.06	590.87	1062.56	1571.77	2082.16	2523.72	2802.72
RIFORNITORE TIF	90203	401937	184	46984.00	35.62	82.48	202.59	408.89	819.54	1335.59	1834.14	2332.58	2840.13	3213.38
STINTINO	81353	405215	35	943	51.52	108.96	245.86	472.43	883.42	1456.85	2097.93	2740.18	3301.91	3685.62

Figure 43 - Example of calculating climatology NHH 8, 26, 35 for some stations

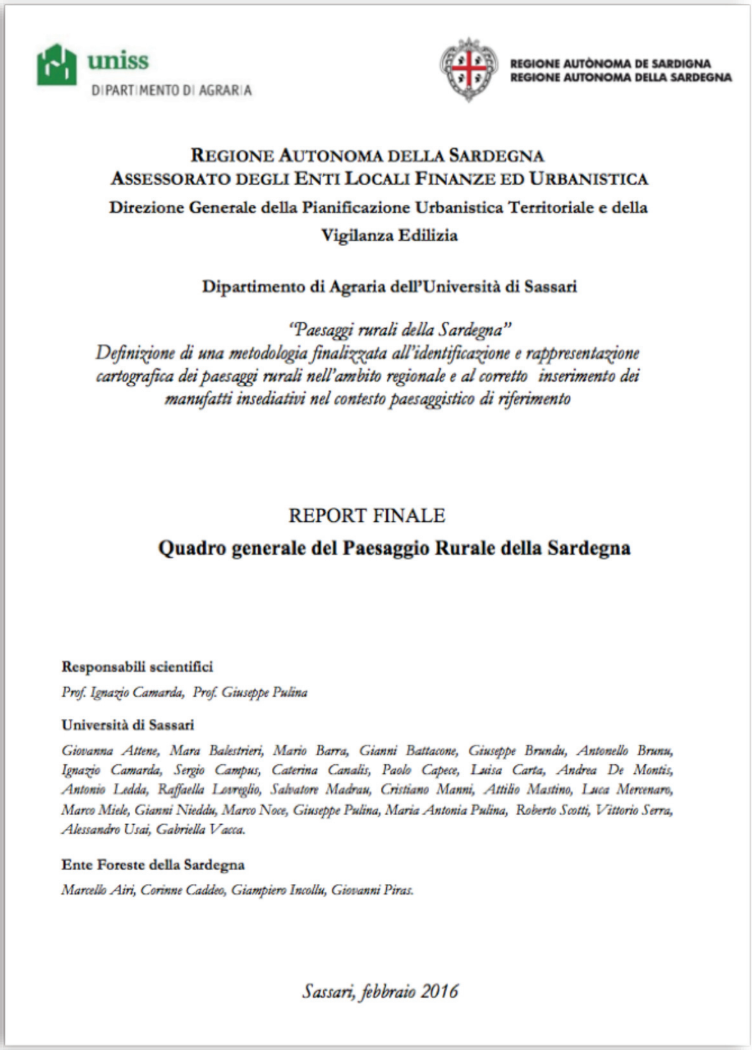
Objective III: extend the result from single points to larger areas

Sardinia: The 1971-2000 characterisation

With a 40-meter resolution pixel across the study area, the following maps were calculated and produced for 1971-2000 climatology:

- average annual maximum temperature
- annual average temperature
- minimum average temperature
- cumulative average annual precipitation
- water deficit from April to September
- potential photosynthetically active radiation for April to September
- thermal sums in 10 °C base
- Normal Heat Hours (sample)
- Huglin Index
- Fregoni Index simplified.

The maps produced, which for the first time with a resolution of 40 m instead of 250 meters, were published into the *A general overview of the agrarian landscape of Sardinia*, by the Department of Agriculture - Uniss and Region Sardinia.



uniss
DIPARTIMENTO DI AGRARIA

REGIONE AUTÒNOMA DE SARDIGNA
REGIONE AUTONOMA DELLA SARDEGNA

REGIONE AUTONOMA DELLA SARDEGNA
ASSESSORATO DEGLI ENTI LOCALI FINANZE ED URBANISTICA
Direzione Generale della Pianificazione Urbanistica Territoriale e della Vigilanza Edilizia

Dipartimento di Agraria dell'Università di Sassari

"Paesaggi rurali della Sardegna"
Definizione di una metodologia finalizzata all'identificazione e rappresentazione cartografica dei paesaggi rurali nell'ambito regionale e al corretto inserimento dei manufatti insediativi nel contesto paesaggistico di riferimento

REPORT FINALE
Quadro generale del Paesaggio Rurale della Sardegna

Responsabili scientifici
Prof. Ignazio Camarda, Prof. Giuseppe Pulina

Università di Sassari
Giovanna Attene, Mara Balestrieri, Mario Barra, Gianni Battacone, Giuseppe Brundu, Antonello Brunu, Ignazio Camarda, Sergio Campus, Caterina Canalis, Paolo Capece, Luisa Carta, Andrea De Montis, Antonio Ledda, Raffaella Lovreglio, Salvatore Madrau, Cristiano Manni, Attilio Mastino, Luca Mercenaro, Marco Miele, Gianni Nieddu, Marco Noce, Giuseppe Pulina, Maria Antonia Pulina, Roberto Scotti, Vittorio Serra, Alessandro Usai, Gabriella Vacca.

Ente Foreste della Sardegna
Marcello Airi, Corinne Caddeo, Giampiero Incollu, Giovanni Piras.

Sassari, febbraio 2016

Figure 44 - ***A general overview of the agrarian landscape of Sardinia***
Department of Agriculture - Uniss and Region Sardinia

Average annual maximum temperature

The average annual maximum temperature shows the presence of variables annual averages between 19 and 20 °C in coastal areas of Nurra, while in the inland areas there was an increase of these values up to 23 °C. The trends observed for the maximum temperatures, in equal proportion and conditions, is that of a progressive increase correlated with the distance from the sea and which varies with the exposure and the distance from the valley floor.

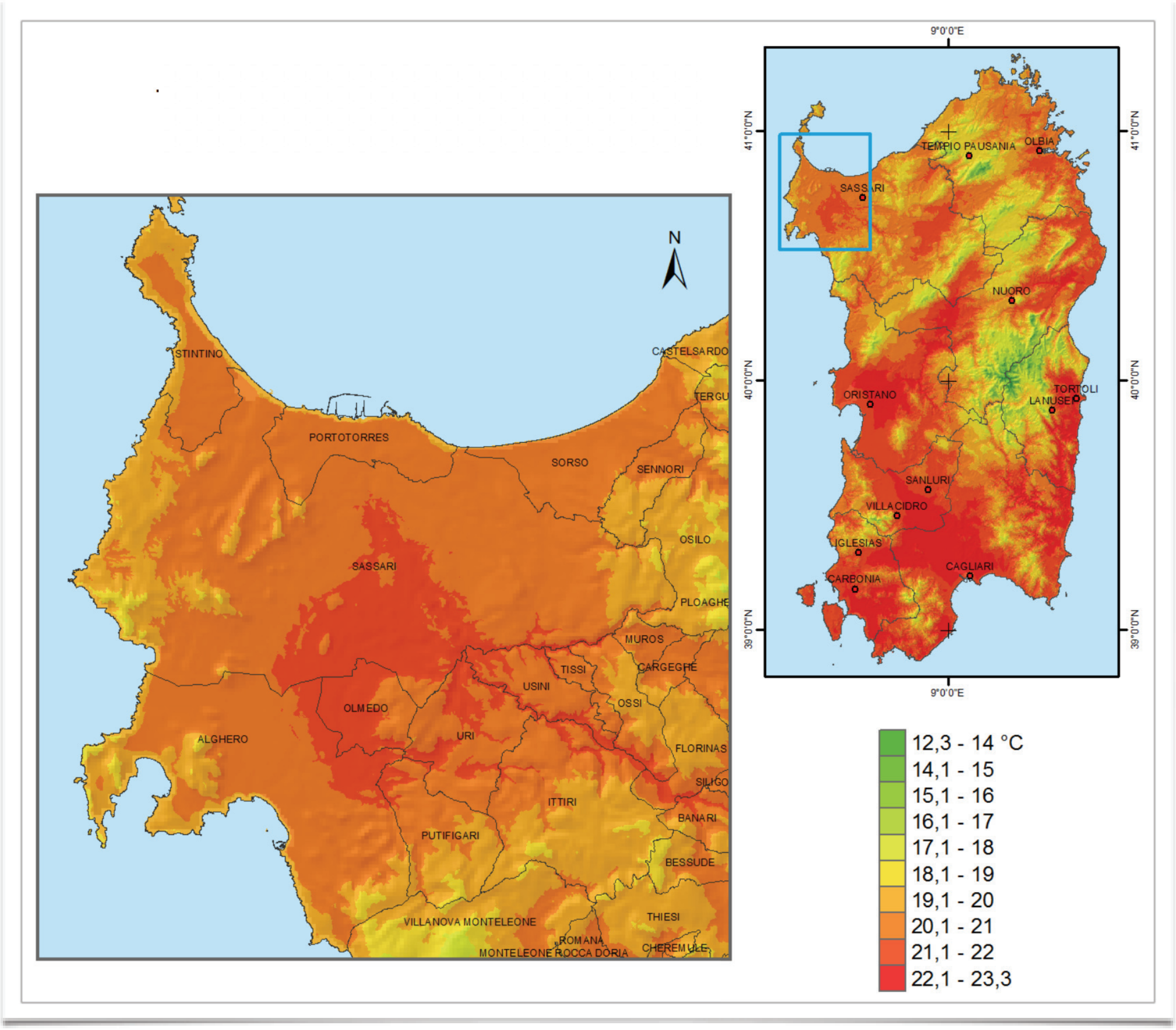


Figure 45 - Average annual maximum temperature

Annual average temperature

The average annual temperature of Nurra is on average equal to 15-16 °C. In the coast it arrives at amounts equal to 17 °C, while in the interior and hilly areas does not exceed 15 °C.

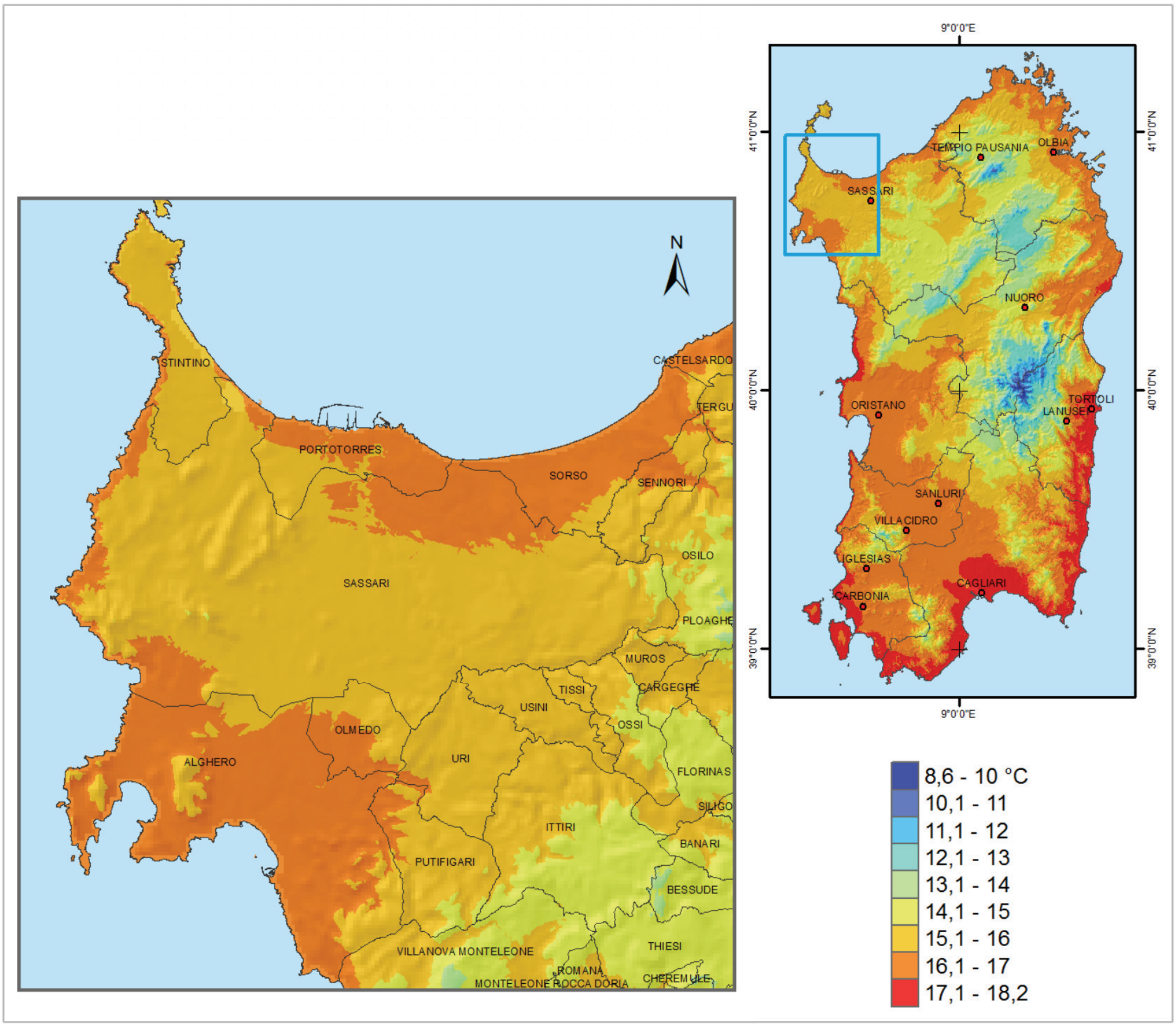


Figure 46 - Annual average temperature

Minimum annual average temperature

Minimum average annual temperature reaches a value of 14-15 °C in coastal areas, while progressing towards the inside, the value is reduced significantly up to 10 °C. Compared to the maximum temperatures shows a reverse trend for the influence it exerts on temperatures in the heat capacity of the ocean. Morning temperatures will also reduce significantly with increasing altitude and according to the exposure of the slope.

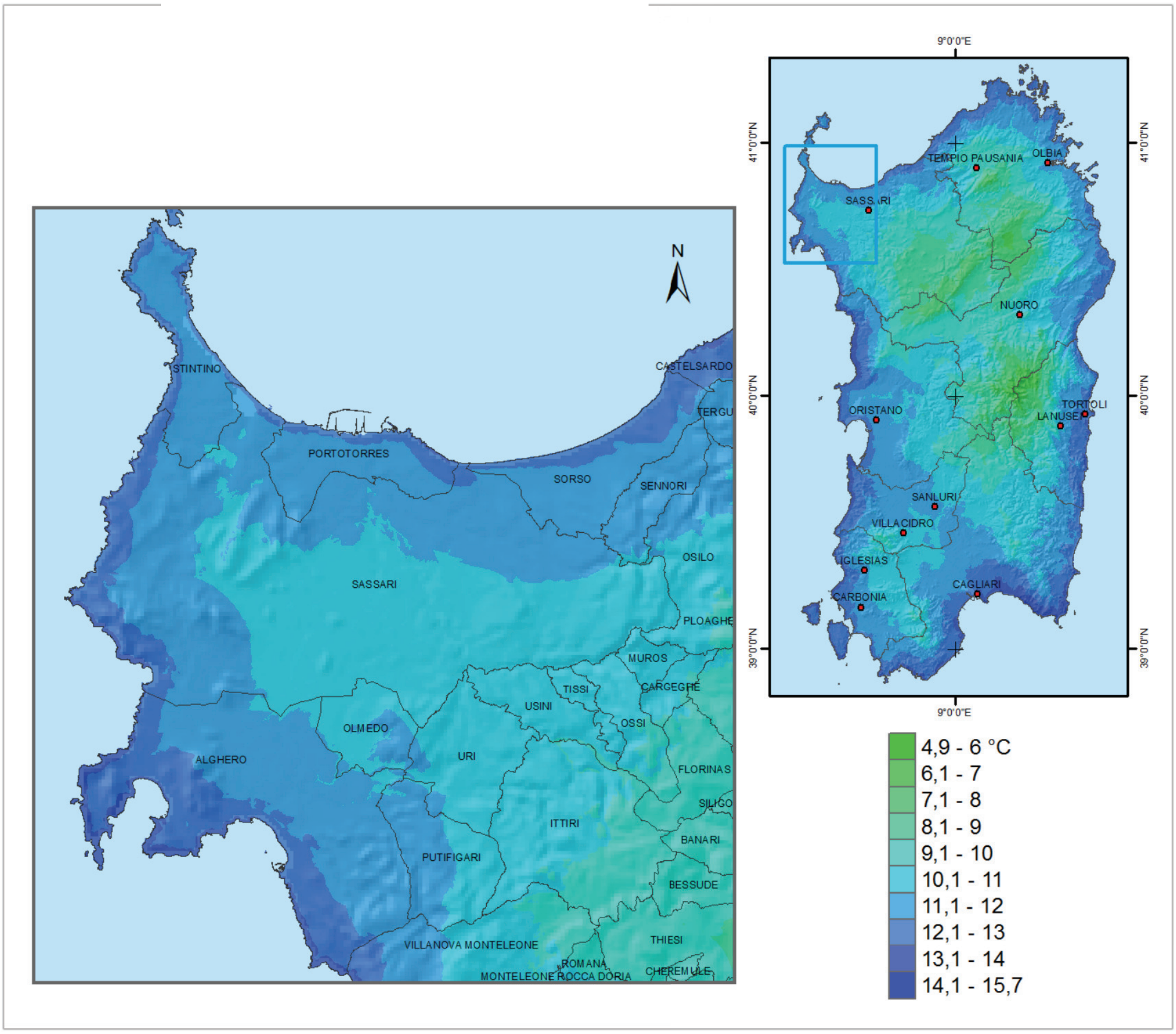


Figure 47 - Minimum annual average temperature

Annual cumulative average precipitation

The annual rainfall of Nurra, related to climatology 1971- 2000, ranging between 500 mm of flat areas and more than 600 mm in the hilly areas.

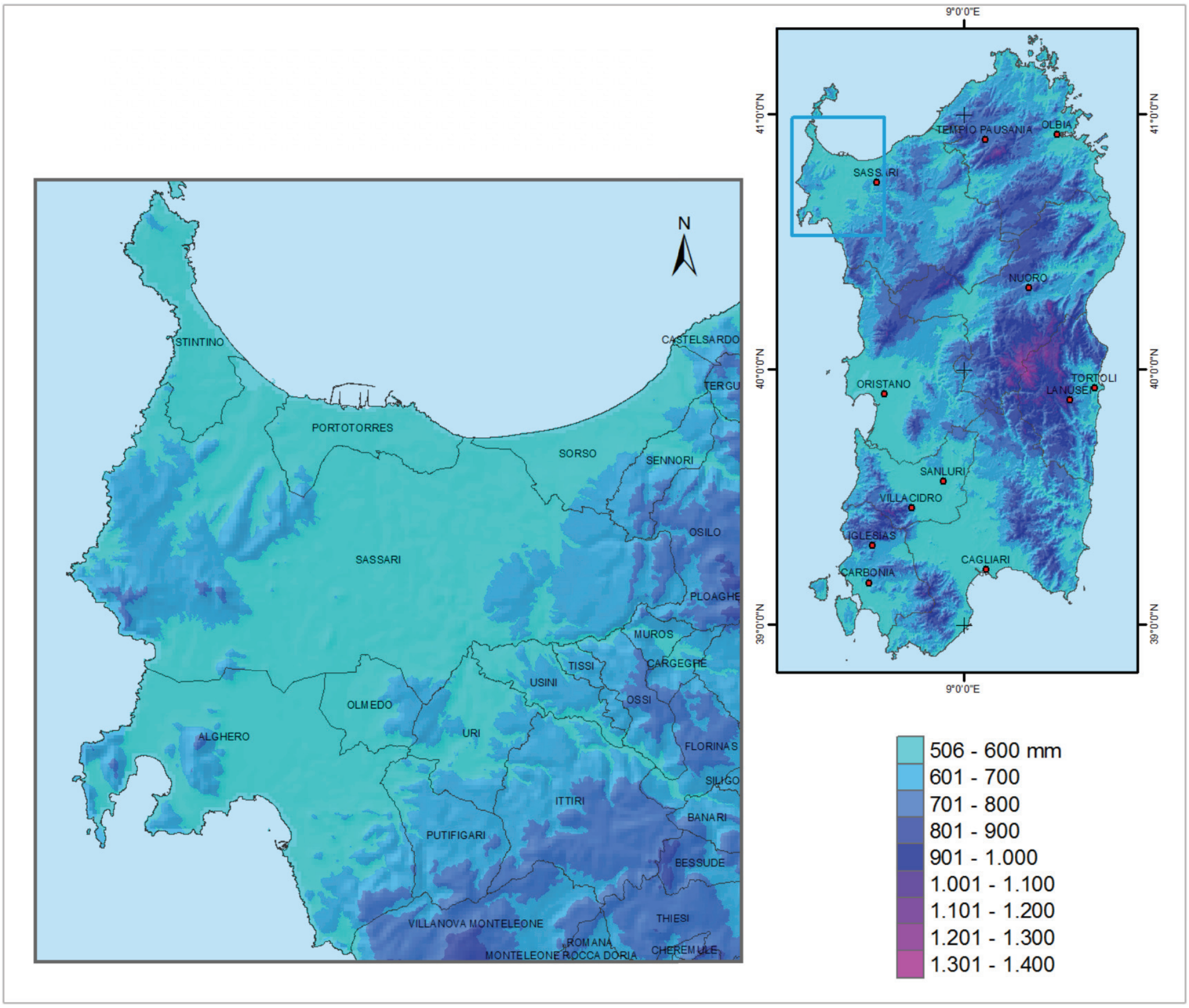


Figure 48 - Annual cumulative average precipitation

In Sardinia, as shown by some climatograms of Walter and Lieth calculated, during the summer months the hydrometeorological balance goes to the negative for the high evapotranspiration and the low precipitation. The central part of the Nurra is those with the highest water deficit between april to september.

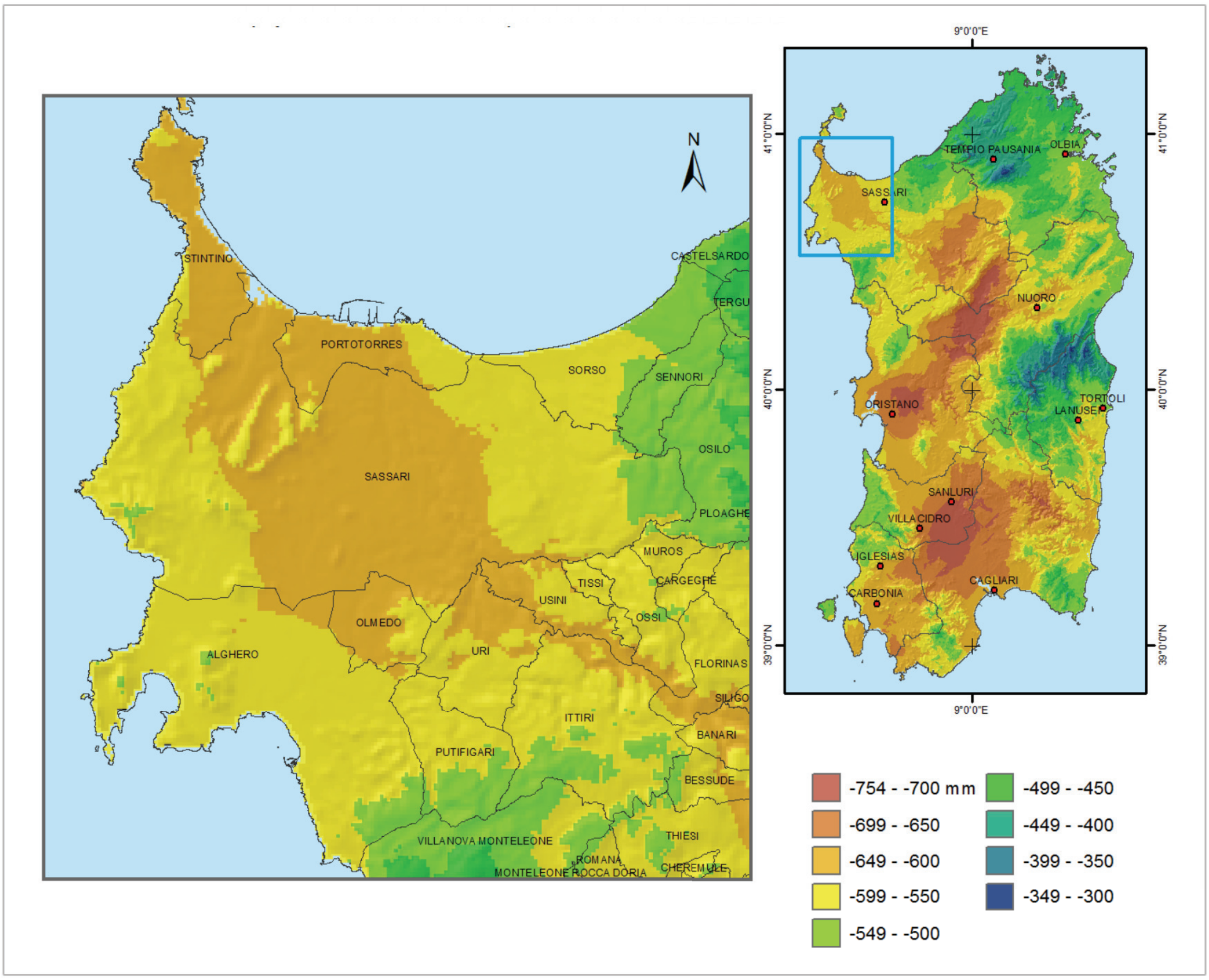


Figure 49 - Water deficit from April to September

Potential photosynthetically active radiation for April to September

The PPAR values for the areas considered are approximately 450000 WH / m2. Areas with a slope of 15% and exposed to the south reach 550000 WH / m2.

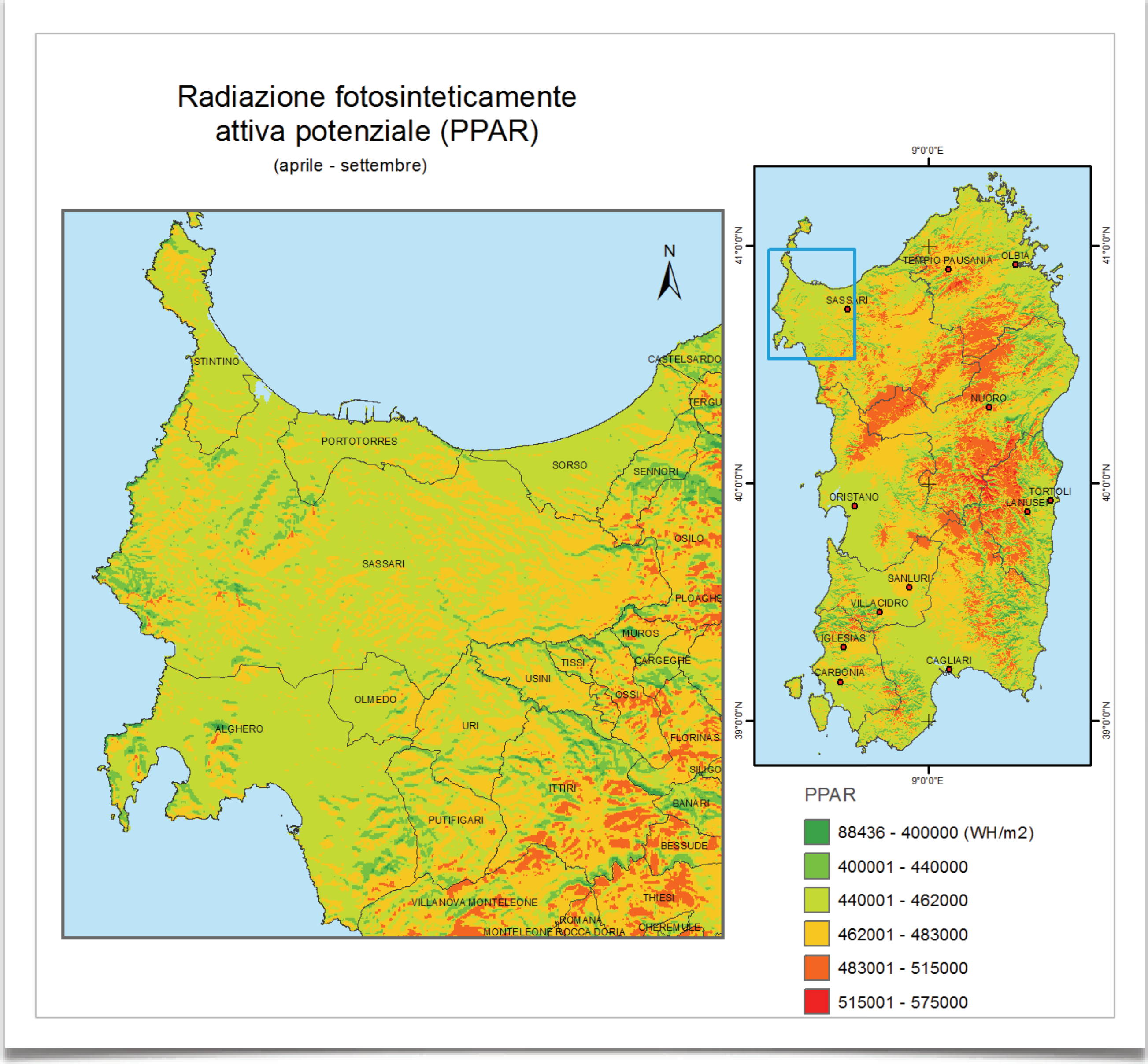


Figure 50 - Potential photosynthetically active radiation for April to September

Normal Heat Hours (sample on 10 june)

In this elaboration, the function used to convert the temperature data in normal hot hours using a minimum cardinal temperature of 10 °C, a cardinal maximum temperature of 35 °C and an optimum temperature of 26 °C (July-August). It is an example of heat accumulation to June 10 of a typical year, in which there is a clear relation with the territory of the ONC, altitude and distance from the sea.

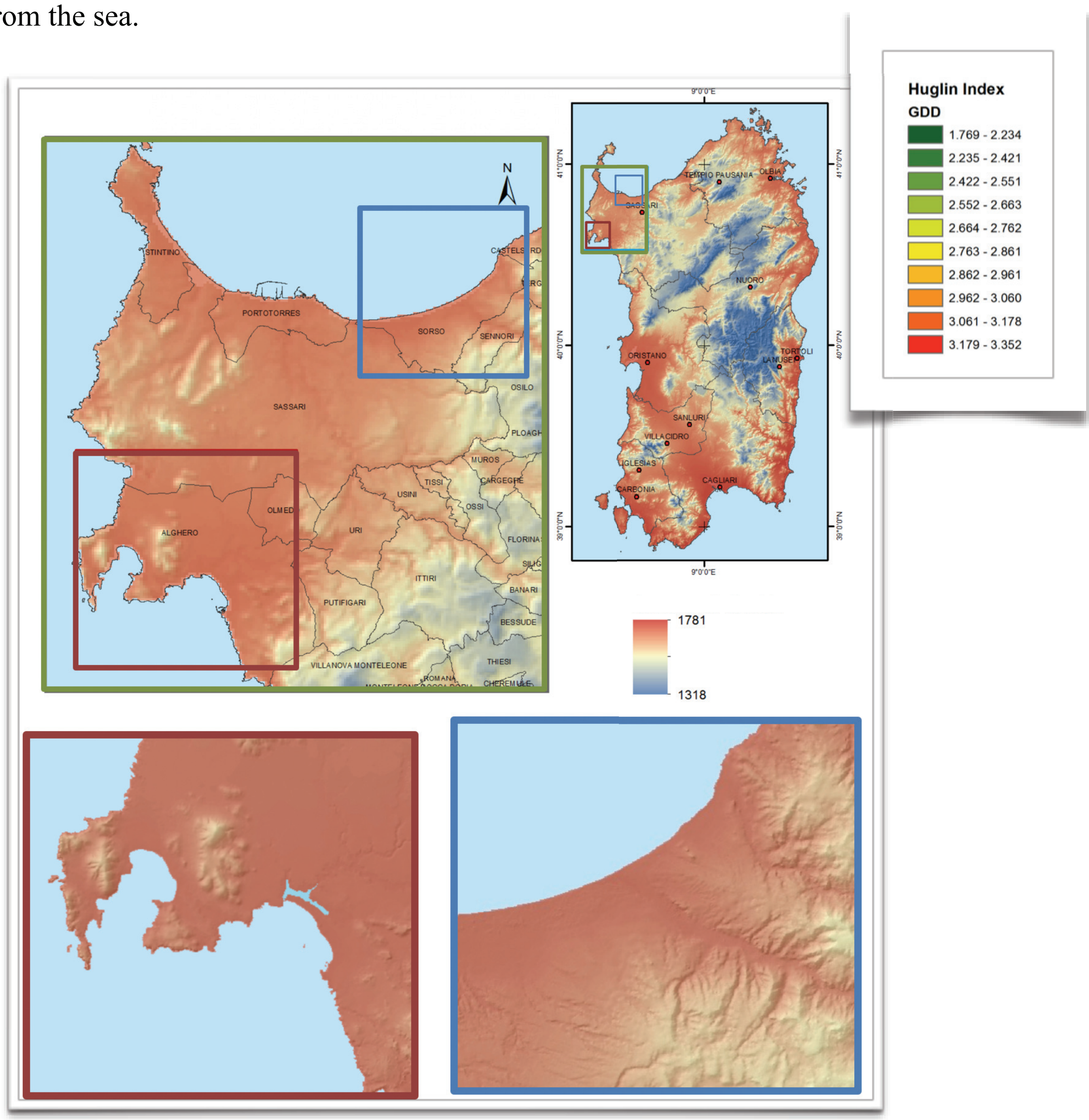


Figure 51 - Normal Heat Hours (sample on 10 june)

In the top right there are NHH reports throughout Sardinia. In the upper left, the study area of Nurra. In the lower left, the test area of Alghero and in the lower right Sorso Sennori.

Huglin index

The index shows the HI values very high, higher than in 2000 in most of the territory; This allows you to precisely define the useful areas to suit all wine objectives. In the figures at 40 m resolution, you can appreciate the little suitability microclimatic differences owed on the aspect and distance from the sea

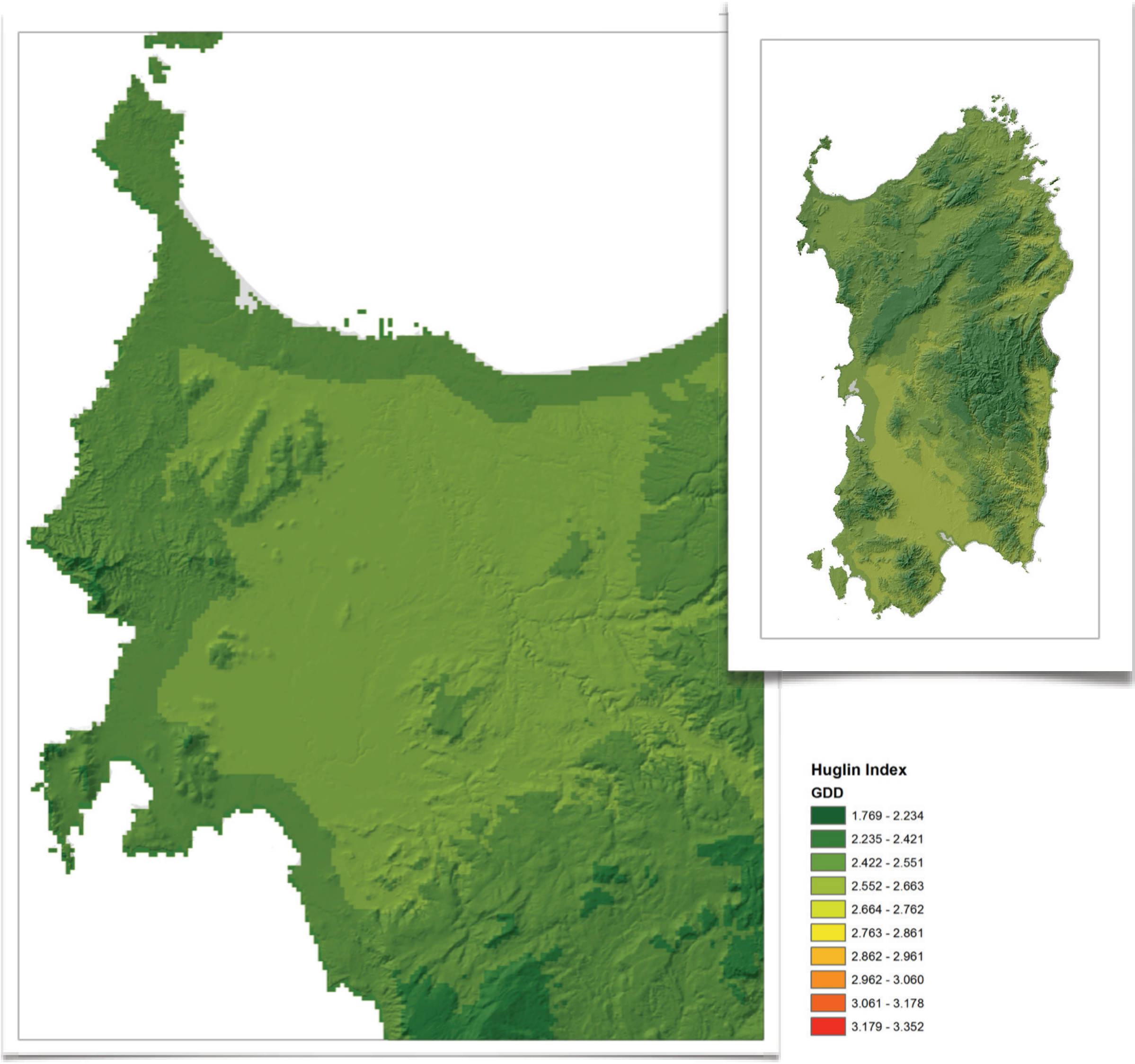


Figure 52 - Huglin Index
In the top right there are IH reports throughout Sardinia. In the upper left, the study area of Nurra.

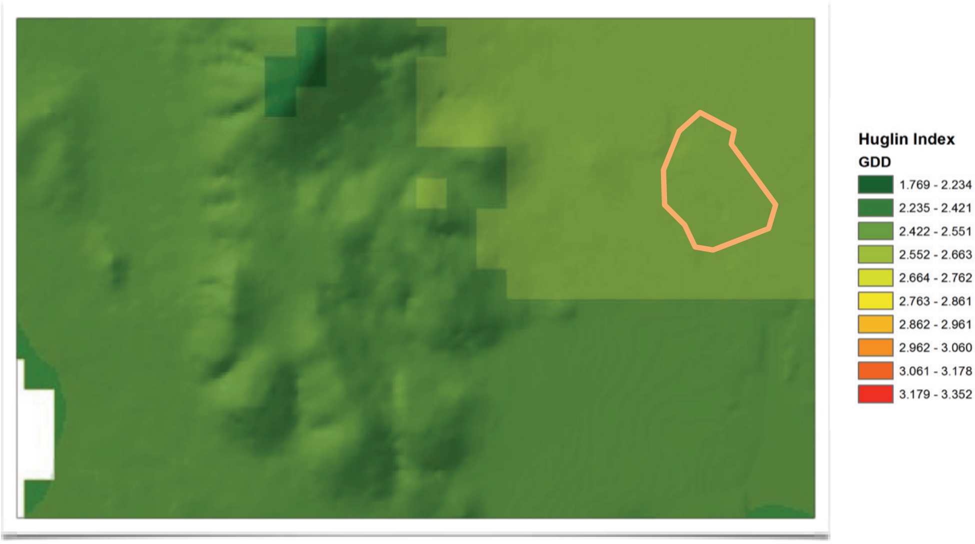


Figure 53 - Detail of Huglin Index for Sella and Mosca area.

IH for Sella and Mosca area is 2535. In figure 53 it is represented by a poligon.

The index values in the coastal area are low, while reaching high thermal excursion values in the most indoor, hilly and mountainous areas. The index appears unsuitable to describe this type of situation. It is more appropriate to evaluate the vocation of different territories on different continents, countries or regions.

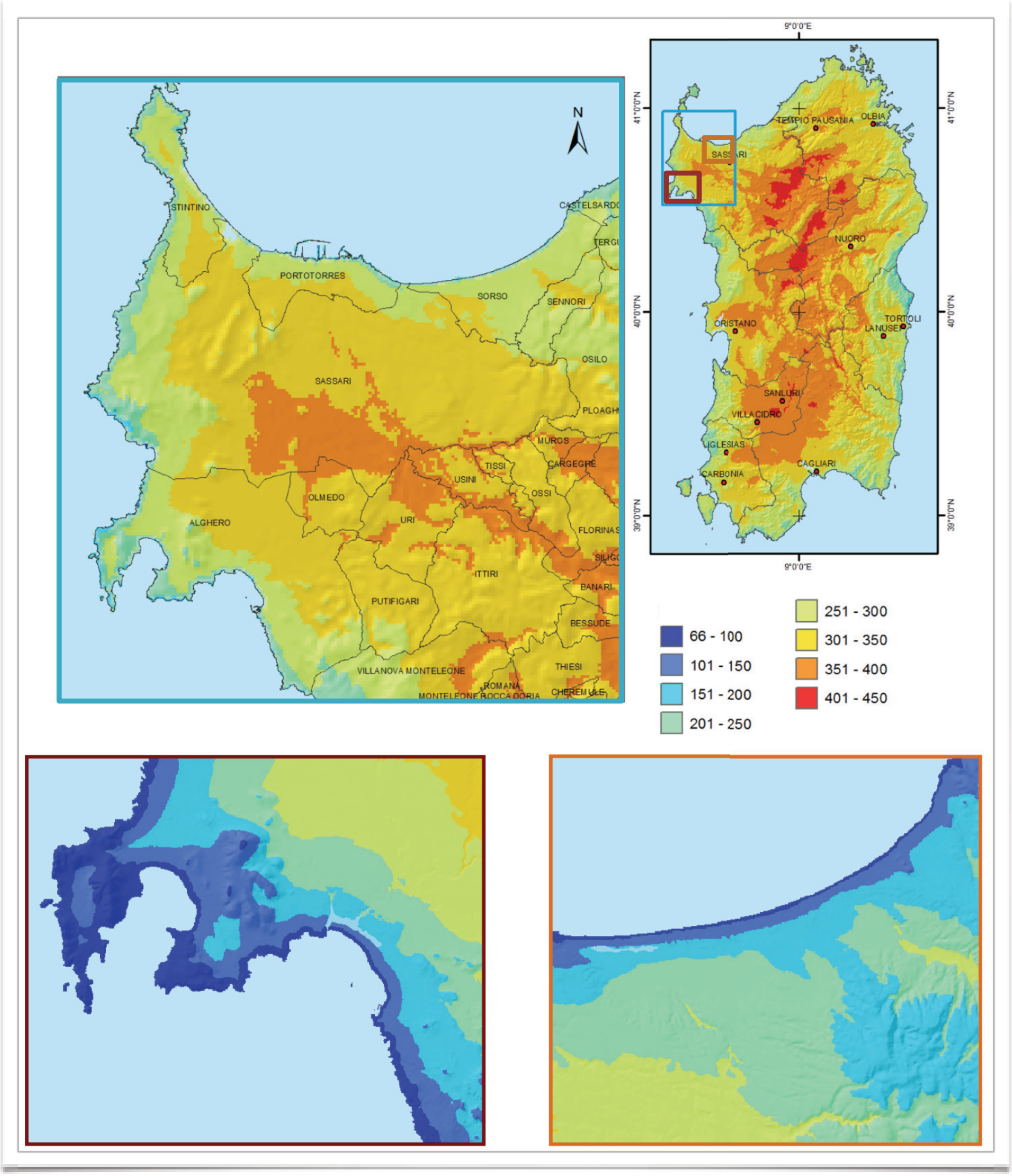


Figure 54 - Fregoni Index

In the top right Index is reports throughout Sardinia. In the upper left, the study area of Nurra. In the lower left, the test area of Alghero and in the lower right Sorso Sennori.

The yellow color (301-350) shows the attitude of the red wines for ageing. Therefore it is appropriate to reallocate the area to red wines.

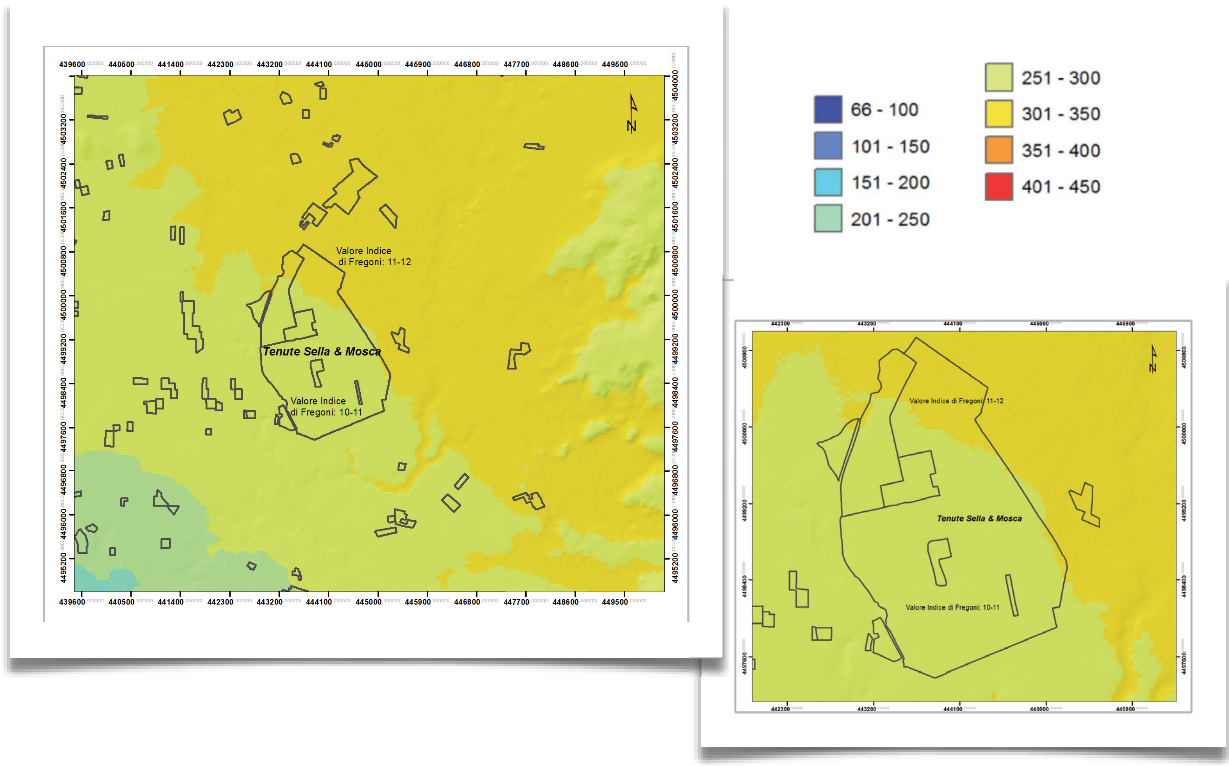


Figure 55 - Detail of Fregoni Index for Sella and Mosca area
The grey lines represents the vineyards.

France: the case study of Buzet

During the time at University of Reading, from the 21st of May to the 28th October 2016, I worked with the supervision of Dr. Martin Lukac and Dr. Jake Bishop at the School of Agriculture an ongoing research project AgriCLASS, and we are in the process of developing an agro-climatic characterisation of vineyards in Buzet, France. Buzet-sur-Baïse is a town of 1,275 inhabitants located in the department of Lot-et-Garonne in the Aquitaine region.

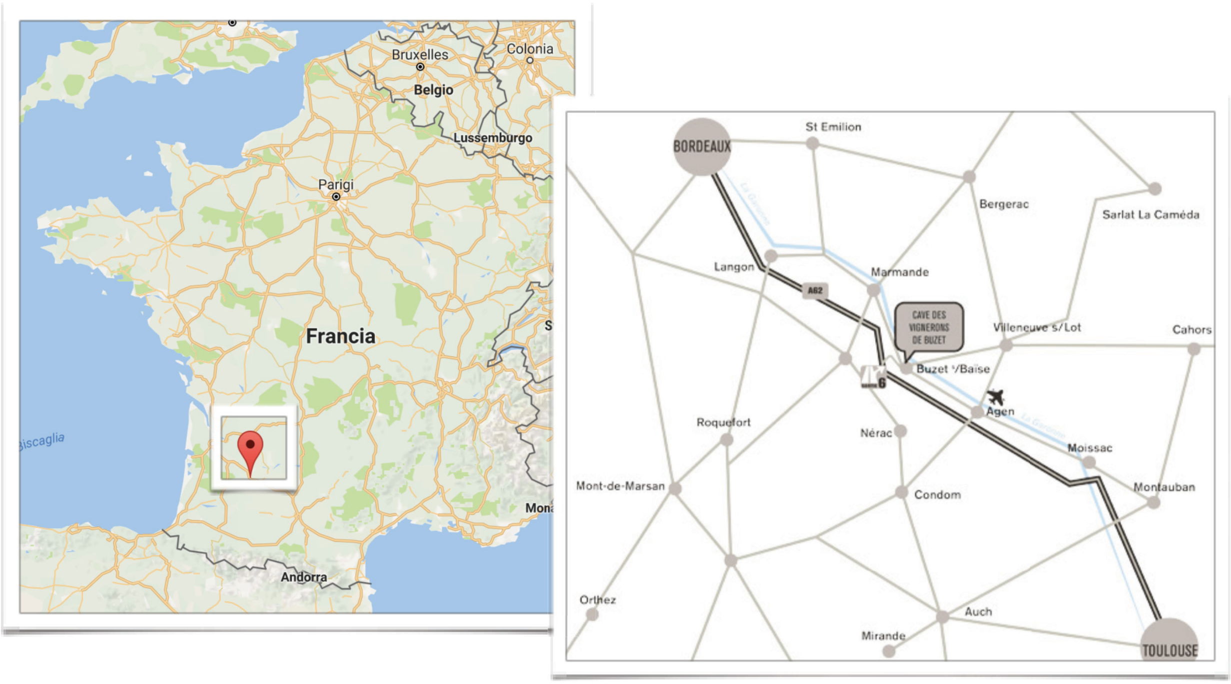


Figure 56 - The Buzet Region in France

The Buzet wine appellation, Cave Coopérative de Buzet, is based in South-West France. Anchored to the hill slopes above the River Baïse, halfway between Bordeaux and Toulouse, the Buzet appellation covers about 2000 hectares not far from the Garonne. The pedology is a mix of alluvial soils, clay, floods, and clayey limestone. The hills higher reach a quota of 150 meters above sea level.

In 1953, these people decided to join forces and set up a cooperative. The Vignerons de Buzet[24] winery was born. Buzet wines have come a long way since then and were awarded the Appellation d'Origine Contrôlée (AOC) label in 1973. The region actually comprises 180 farms over 1850 hectares specializing in red wine production.

[24] vignerons-buzet.fr

The three most important grape varieties grown in Buzet are Merlot (53% area in 2015), Cabernet Franc (22% area), Cabernet sauvignon (19% area), and - recently introduced - Malbec. The Vigneron de Buzet working with Telespazio for the geo information, New Holland for the agricultural machinery and Frayssinet for the organic fertiliser operate to realise full-scale technological partnerships on vineyards with the aim of optimising the treatment of organic compost of its vines.

The report led by Prof. Martin Lukac with Jake Bishop in May 2016 (in figure 57, Lukac and Bishop, 2016) shows the Buzet vineyards a progressive anticipation of the corresponding phenological phases from 1965 to present. We clearly recognise a phenological trend. Telespazio in November 2016 provided to send me further series of meteorological data for the Buzet area, with the same methodology applied at the Olmedo station and with the NHH resoults confirm a trend of phenological advance. At the same time the results aren't absolutely certainty as in Torbato case. Is it due to the Torbato goals of winemaking and the lack of meteorological stations around the case study area.

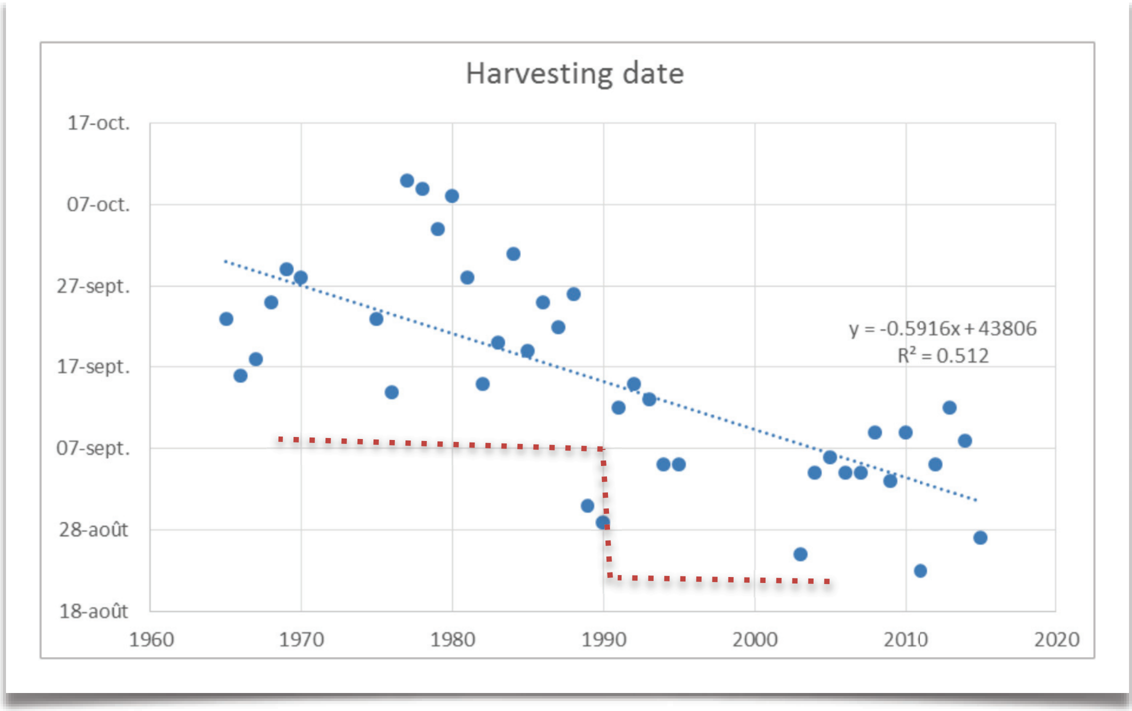


Figure 57 - Initial regression analysis of harvest dates against time for vineyards in Buzet

Telespazio has provided the dataset thermal data every 6 hours for two stations in the Buzet area. And, similarly to what was done for Sardinia, the Worldclim data were acquired for the same scenarios GS and HE. However, the lack of an adequate climatology for Buzet area made weak thermal shift procedure. Compared to Sardegna, the climate of France is more continental, therefore Worldclim's thermal increases are more robust for the same GS and HE scenarios due to the lack of coastal mitigation and the proximity of the Pyrenees. Analysis of breakpoints, as well as for the case of Sardinia shown in Objective 1, may also have occurred in France and study are in progress. The dotted red line in Figure 57 shows a possible breakpoint for France.

Objective IV: analyse a range of scenarios on climatic changes

For GCMs outputs at 30 seconds of resolution acquired on World Clim, a downscaling was performed and the models were calibrated, ie bias correction was made, using WorldClim 1.4 as the 'current' baseline. The weather-weather magnitudes considered were the maximum and minimum temperature, precipitation.

The reference period chosen for statistical downscaling is 2050 (average of 2041-2060) at the largest scale (30 seconds).

The 30-second scenario data was then imported into the Esri ArcGis 10.3 system. The difference between the mean value of the scenario for Sardinia and the average climatological temperature of that month for the 1971-2000 climatology was calculated. It has been worked on the average value of Sardinia to avoid mistakes due to different initial resolutions.

Scenarios

GS		
month	average max	average min
february	1.6	1.619
march	1.96	1.94
april	1.8	1.77
may	1.78	1.79
june	2.03	2.06
july	1.822	1.758
august	1.601	1.6
september	1.697	1.6
october	1.6	1.603

HE		
month	average max	average min
february	2.3	2.977
march	2.19	2.07
april	2.35	2.86
may	2.77	2.52
june	3.445	3.19
july	3.939	3.51
august	4.368	3.875
september	4.05	3.815
october	3	3.079

Figure 58 - Increase in temperatures in 2050 obtained using the two different scenarios

The GS RCP 2.6 scenarios foresees low future emission levels, predicts that the planet Earth will assume ethical and ecological attitudes and commit itself to reducing emissions. The thermal increments of the minimum temperatures range from 1.6 °C in August and September to 2 °C for

December. The maximum temperature increases from 1.6 °C in the months of February, October and November, up to 1.96 °C in March and 2.03 ° C in June.

The HE 8.5 scenario is a particularly negative scenario where emissions continue to increase and energy policies are not welcomed by governments on the planet earth, leading to considerable tombstone overheating. This severely affects the temperatures. Monthly average minimum temperatures increase from 2.5 °C in December to 3.87 °C in August and September. The maximum temperatures increase from a minimum of 2.28 °C in January, reaching an incidence of 3.9 °C in July, 4.36 °C in August and 4.05 °C in September.

Σ NHH

code station	station	long	lat	quote	distance from the sea	HE 8 22 35 gen	HE 8 22 35 feb	HE 8 22 35mar	HE 8 24 35 gen	HE 8 24 35 feb	HE 8 24 35 mar	HE 8 24 35 apr	HE 8 24 35 mag	HE 8 24 35 giu	HE 8 24 35 lug
CA011B097	MANDAS F.C.	90753	393942	491	44.337	172.86	376.68	685.69	106.41	238.03	455.62	804.66	1374.14	2000.83	2531.71
CA027B177	SANLURI O.N.C.	85039	393143	68	33.419	266.54	558.35	968.81	186.08	394.11	707.93	1157.74	1755.32	2337.73	2808.69
CA035A003	CAPO FRASCA	82737	394427	90	858	358.03	714.99	1169.90	243.42	490.72	823.02	1282.69	1918.43	2597.57	3215.43
CA036B012	ARMUNGIA	92245	393125	366	21.879	225.53	472.46	832.13	154.47	329.04	606.00	1005.82	1589.31	2177.08	2633.91
CA047B226	VILLACIDRO F.C.	84436	392750	213	26.660	379.07	771.79	1279.50	263.47	545.98	936.45	1451.43	2110.59	2703.65	3128.37
CA050A398	CAPO S.LORENZO	93749	392957	12	355	373.24	740.56	1205.67	268.01	534.53	891.08	1359.91	1986.80	2617.17	3145.11
CA052B064	FLUMINIMAGGIORE	82959	392615	45	7.434	298.20	617.49	1043.51	216.32	448.55	777.93	1230.36	1835.14	2441.60	2969.32
CA054B109	MURAVERA	93349	392528	19	5.124	318.34	664.57	1111.13	227.89	479.75	825.79	1299.26	1914.76	2491.11	2942.42
CA059A005	DECIMOMANNU	85803	392042	23	18.164	268.78	554.08	941.43	191.25	400.13	701.05	1130.86	1721.78	2307.81	2781.75
CA067B082	IGLESIAS	83222	391838	193	8.964	299.42	626.22	1065.82	207.87	436.78	767.36	1221.75	1842.56	2456.73	2940.33
CA069B312	DECIMOMANNU (VIVAIO)	85817	391759	15	13.943	287.22	604.78	1043.25	209.03	446.58	794.82	1255.83	1862.66	2440.02	2899.60
CA073B050	CORONGIU	91653	391842	126	10.160	346.28	697.09	1165.53	243.08	492.19	849.94	1340.54	1985.35	2580.30	3021.25
CA073B171	SA PIRA (CASERMA)	91114	391838	215	9.382	358.44	733.86	1230.56	251.69	523.75	910.44	1414.81	2057.92	2638.10	3068.28
CA082A008	CAGLIARI ELMAS	90340	391441	0	4.390	293.13	617.36	1049.44	210.49	444.44	775.07	1232.16	1852.60	2474.88	2994.98
CA082B039	CAGLIARI S.I.	90707	391336	7	1.475	400.18	814.34	1332.01	288.02	595.32	999.13	1515.72	2175.22	2806.60	3317.24
CA089A009	CAPO CARBONARA	93052	390617	118	239	468.65	916.06	1456.91	342.17	674.85	1091.33	1600.60	2268.76	2938.62	3489.02
CA090B046	CARLOFORTE	81847	390815	18	178	440.61	867.21	1388.23	318.21	632.15	1031.41	1533.21	2189.44	2857.94	3440.29
CA092B140	PALMAS SUERGIU	83331	390411	12	2.224	309.88	637.13	1066.50	225.94	466.13	799.59	1268.92	1876.96	2468.90	2958.10
CA102B148	PISCINAMANNA	85513	385935	255	5.674	308.90	643.34	1067.01	224.26	469.65	798.89	1240.00	1834.17	2418.86	2872.23
CA104B085	IS CANNONERIS	85113	390210	716	13.090	103.35	230.15	455.99	57.71	130.94	278.22	553.92	1088.01	1735.12	2340.82
CA105B047	CASTIADAS	92952	391413	167	6.263	263.78	555.42	944.29	175.27	372.16	653.48	1068.55	1663.42	2300.15	2867.44
NU001B204	NTE PEDROSU - SUARED	93914	405033	96	1.573	309.26	654.92	1088.40	222.13	470.80	799.58	1252.32	1865.55	2501.59	3015.76
NU002B035	BUDONI (C.RA)	94156	404237	20	1.442	321.49	665.96	1108.30	218.61	459.20	787.57	1243.96	1865.57	2516.61	3095.21
NU011B129	ORUNE	92207	402427	745	26.674	158.62	319.08	568.80	96.94	194.73	361.44	647.84	1163.97	1792.62	2421.68
NU016B126	OROSEI	94156	402250	19	2.411	367.06	747.69	1231.48	267.71	550.12	927.81	1423.83	2069.03	2692.13	3194.45
NU019B116	NUORO	91917	401916	545	26.766	142.83	299.81	576.80	87.06	184.36	379.02	721.41	1290.80	1895.42	2377.12
NU034B095	MACOMER	84654	401604	565	25.240	134.86	304.71	595.90	81.53	189.05	397.60	739.95	1296.08	1887.34	2374.61
NU048B065	FONNI	91519	400704	992	32.936	40.28	94.68	248.98	19.41	46.99	141.29	357.46	869.92	1517.24	2157.14
NU051B071	GENNA-SILANA (C.RA)	93031	400934	1.010	10.915	29.15	59.37	169.12	13.46	27.44	91.88	254.99	693.74	1316.61	1983.54
NU060B054	DESULO	91351	400056	920	38.911	99.11	217.02	449.79	59.31	132.36	295.76	549.07	1035.82	1635.13	2192.58
NU065B051	COSSATZU (C.RA)	91052	395638	860	43.133	94.17	212.12	422.92	54.74	126.87	269.41	523.55	1025.93	1636.65	2191.22
NU067B101	MEANASARDO	90425	395646	585	45.385	171.88	358.19	658.47	105.17	222.86	432.70	784.93	1363.87	1995.69	2530.66
NU068A007	CAPO BELLAVISTA	94251	395553	155	376	382.96	768.72	1247.59	265.22	539.80	896.65	1379.16	2025.37	2694.84	3276.32
NU069B014	ARZANA	93144	395505	674	13.297	195.89	373.51	685.93	123.54	232.93	447.37	827.53	1418.68	2072.07	2660.71
NU073B090	LANUSEI	93219	395247	595	12.288	213.48	432.45	758.74	139.95	285.22	519.77	887.26	1466.41	2107.35	2666.82
NU076B180	SANTA SOFIA	90760	395206	825	46.769	71.17	157.99	341.15	39.46	89.84	211.19	428.09	890.35	1484.31	2058.57
NU085B081	JERZU F.C.	93045	394815	550	13.712	238.38	486.78	865.27	159.83	329.72	609.05	1037.71	1649.55	2280.91	2783.21
NU088B231	VILLANOVATULO	91251	394548	347	38.841	174.50	372.99	677.79	112.17	242.94	460.76	806.45	1370.70	1996.20	2559.55
NU090B049	COL.PENALE SARCIDANC	90845	394839	699	44.999	97.21	219.41	439.19	56.50	130.37	279.21	542.46	1041.44	1645.75	2205.42
NU091B118	NURRI F.C.	91349	394320	557	36.640	117.83	265.66	529.84	70.53	163.39	348.77	654.08	1188.98	1803.42	2339.73

Figure 59 - Example of calculation of NHH in HE scenario for the different stations

Similarly to what was done for the climatology 1971-2000, the NHHs were calculated for the different thermal thresholds for GS and HE models:

NHH 8,22,35 GS for the months of January, February and March

NHH 10,22,35 GS for the months of January, February and March

NHH 8,26,35 GS for the months from January to October

NHH 10,26,35 GS for the months from January to October

NHH 8, 24,35 GS for the months from January to October

NHH 10,24,35 GS for the months from January to October

NHH 8,22,35	HE for the months of January, February and March
NHH 10,22,35	HE for the months of January, February and March
NHH 8,26,35	HE for the months from January to October
NHH 10,26,35	HE for the months from January to October
NHH 8, 24,35	HE for the months from January to October
NHH 10,24,35	HE for the months from January to October

Maps are reported in the analysis of the results.

Analysis of the results

Considerations on the sprouting of the grape

NHH 10 22 35

Figure 60 shows the map of March 10 22 35 for climatology 1971 - 2000 above. The maximum 1971-2000 values are 566 NHH and the mean values are 270.

The GS model for the same month shows values of 592.61 average and 1187 maximum therefore we find the germination phase with absolute certainty in the previous month, as shown in the figure. The February values for this model are in fact 304 for the average value and 706 for the maximum values.

The HE model for these thresholds shows very high values in March. The maximum values exceed 1300 NHH in some coastal areas the south of Sardinia, 1200 in the Nurra area, although the average regional value is 666.

In this case, the phenological advance is even more abundant than the one shown by the GS model, since in February we already have 365 NHH of average value, compared to the 270 averaged by the climatological map, so reasoning about the values we can say that the phenological advance can exceed 4 weeks.

NHH's maximum values for February are in fact 812. For this reason, the map of January is also reported as reference. The January of the HE model shows an NHH thermal cumulative of 172, with maximum values of around 400 NHH. Considering that the temperatures are also to be taken into account in the months of December and November, this scenario in very hot winters may have the sprouting of the vine at the end of January. This is the case especially of Torbato, Cannonau and Vermentino.

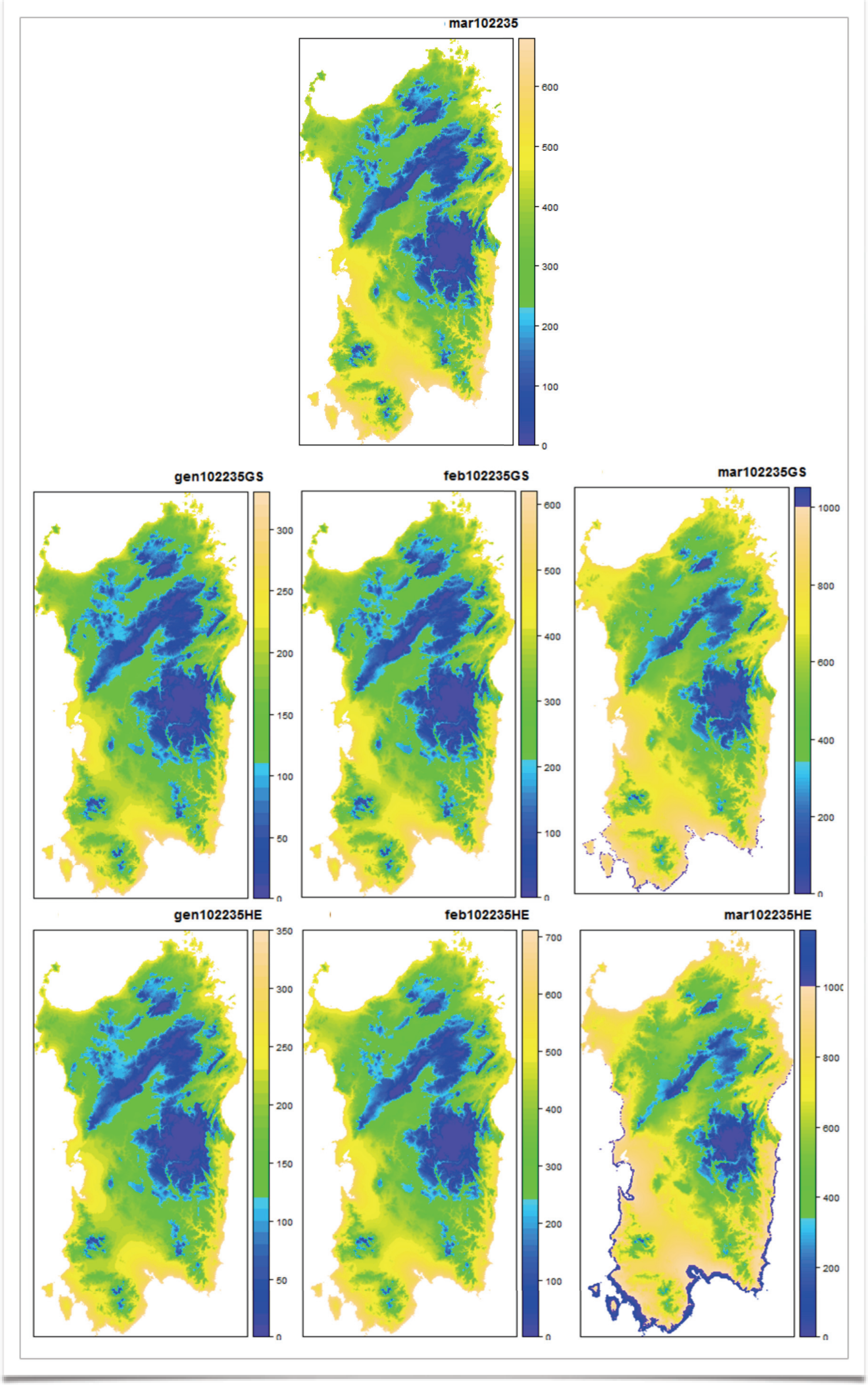


Figure 60 - The sprouting of grape. Results for NHH 10 22 35

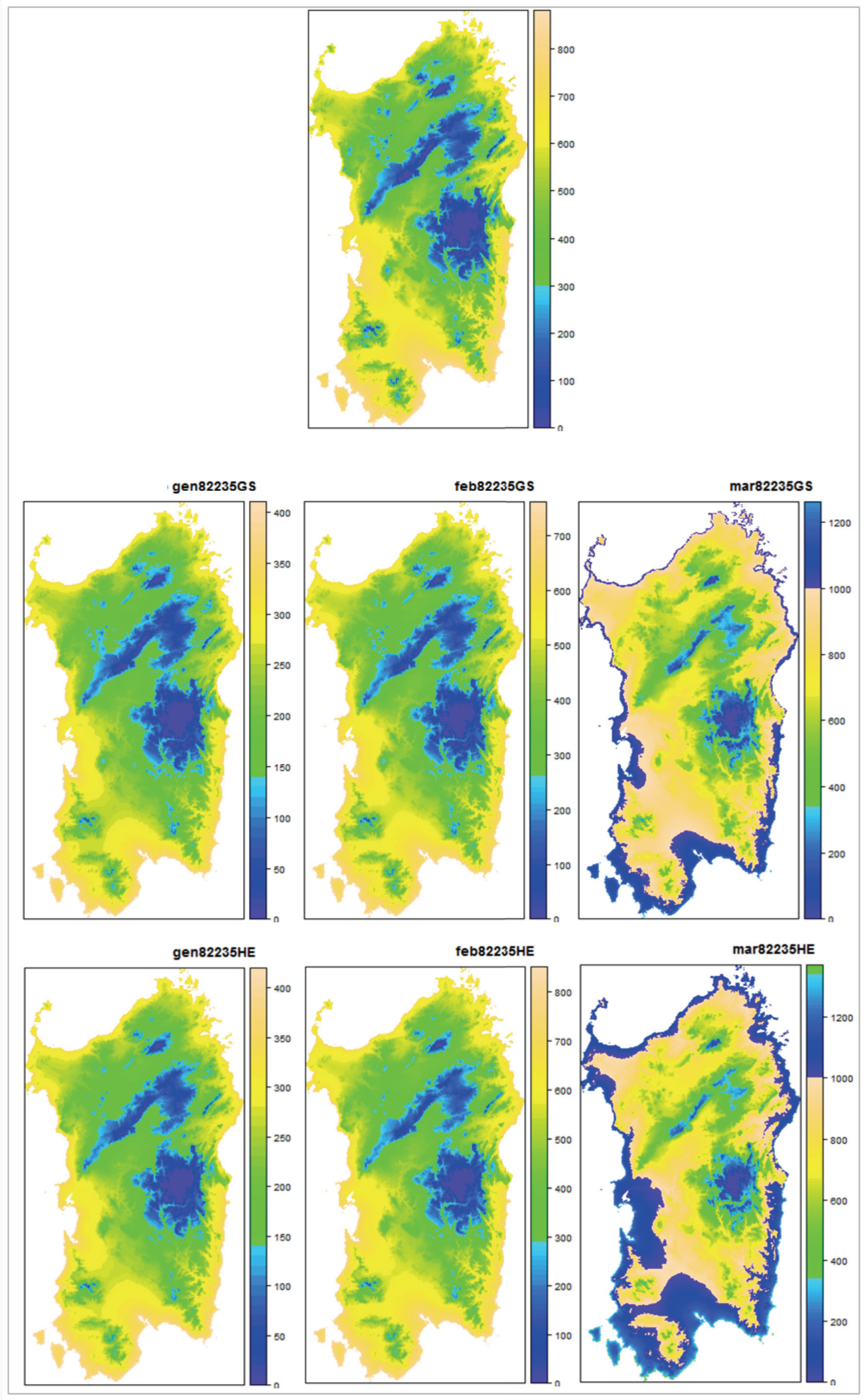


Figure 61 - The sprouting of grape. Results for NHH 8 22 35

NHH 8 22 35

The NHH 1971-2000 for this thermal threshold shows average values in March at 489 and 989 in coastal areas.

The GS model shows average values for March of 770 and maximum values of 1364. In February, the average value is 420 and the maximum value is 835. The phenological advance found is therefore about three weeks .

The HE model shows NHH's maximum values for March of 1456 NHH and mean 851 NHH. Clearly this is evident because early varieties have a lower thermal activation threshold, so it is normal that with 8 ° C instead of 10 ° C there is a greater thermal cumulus. This is the case of Cabernet sauvignon for example. In February, the maximum values of coastal areas are over 900 and the average value is 489. In January, the maximum value is 468 and the average value of 234. With the HE model there is therefore an average phenological advance a month.

Figure 61 showa the 71 2000 climatic value for February and the increase of maximum temperatures in 2050 with the HE scenario.

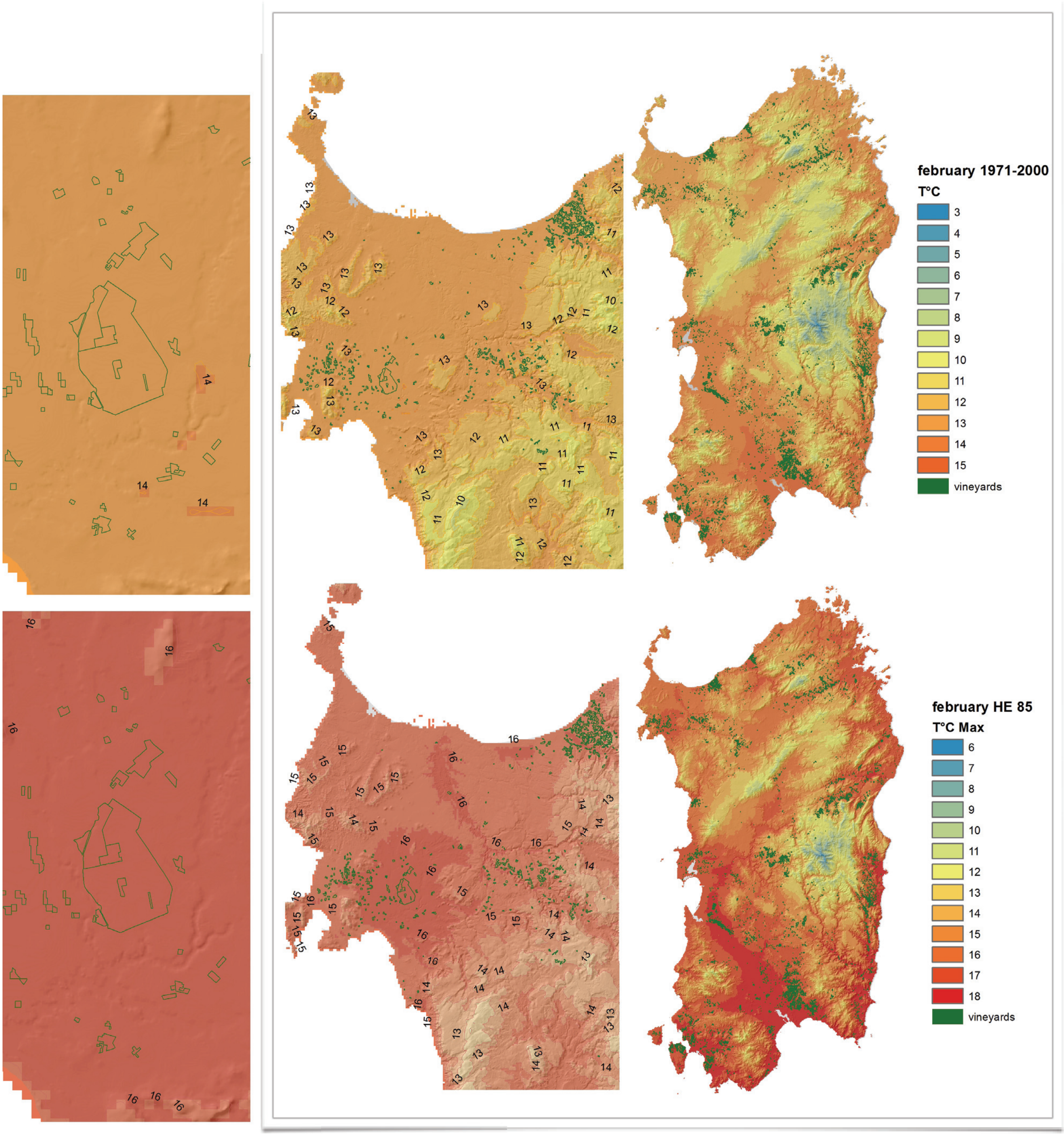


Figure 62 - Temperature of February 1971-2000 compared with the HE scenario On the right Sardinia, in the Middle Nurra, on the left Sella and Mosca area in Alghero.

Considerations on BBCH 65 phase

NHH 8 26 35

Figure 39 about Torbato showed that the BBCH phase 65 usually happens at the end of May.
At the end of May the maximum value of NHH is 995 and the average value 655. The minimum value in the hill areas is 240.

With the scenario GS at the end of May we have 1028 NHH. The maximum value of the GS scenario is 1496 in the south of Sardinia and the minimum value in Silana station is 377.
at the end of April the GS model calculated 572 as average value. 956 as maximum and 103 as minimum. It means that the blossoming with this scenario happens one month before.

HE scenario for the end of May forecasts a mean value of 1140 NHH. Maximum values of 1650 and the lower value of 448. The month of april shows a mean value of 648, a maximum value of 1017 and a minimum value of 130. The advance in the BBCH 65 phase is exactly one month also with this scenario.

NHH 10 26 35

The 1971-2000 NHH mean value for the end of May is 545. The maximum value is 865 and the minimum 181.
The GS model for 2050 calculated for the end of may a value of 890. A maximum value over 1300 and a minimum value of 295. At the end of April the average value calculated is 458. It means that in this case the difference between the current situation and the proposed scenario is 3 weeks. This is confirmed with the results of the 10th of April.

The HE model at the end of May calculated 1000 NHH. The maximum is 1481 NHH and the minimum 359. At the end of april the mean value calculated by the scenario is 528 NHH. The maximum value is 914 and the minimum 73. So the BBCH 65 is to be reached a month before.

Considerations on the harvest of grape in September

NHH 8 26 35

The 1971 2000 values for September with the 8 26 35 thresholds show a regional NHH average of 2879 and a maximum coastal value of 3546.

With the increase due to the climatic scenario GS, in the month of September NHH average values increase to 3401 and the maximum values are 4188 NHH.

In August GS scenario has a main value of 2824, a maximum value of 3500 and a minimum value of 2122. In this case study the harvest of Grape happen at the end of august. Exactly one month before.

The HE scenario for September shows an average value of 3459 and a maximum value of 4177.

In august it shows a mean value of 2853, maximum values of 3500 and minimum value of 2276.

With this scenario the harvest happens 28-29 days before.

NHH 10 26 35

The NHH 1971 2000 for the month of September shows a maximum value in the coasts area of 3348 NHH and 2715 NHH as average value for the Region of Sardinia.

The NHH maximum value for HE scenarios in September is 3996.90 NHH. The average value obtained for Sardinia is 3299 NHH.

The maximum NHH value for the GS scenario is 3999, very similar values. The average value obtained for Sardinia is 3232 NHH.

The HE model shows higher average values not so much in coastal areas where there is some analogy with the GS model as well as in the hilly ones.

NHH 10 24 35

The 1971 Climatology 2000 for this NHH thermal threshold shows average values of 3170 and maximum 3901 in coastal areas. The GS scenario shows average values of 3719 and maximum values of 4554. The scenario HE for september has average values of 3298 and maximum values of 3996. Value are calculated to understand better results of 8 26 35 and 10 26 35. The utility of 10 24 35 could be applied in the case of grape for BBCH 65 and for the olives trees and many other Mediterranean plants.

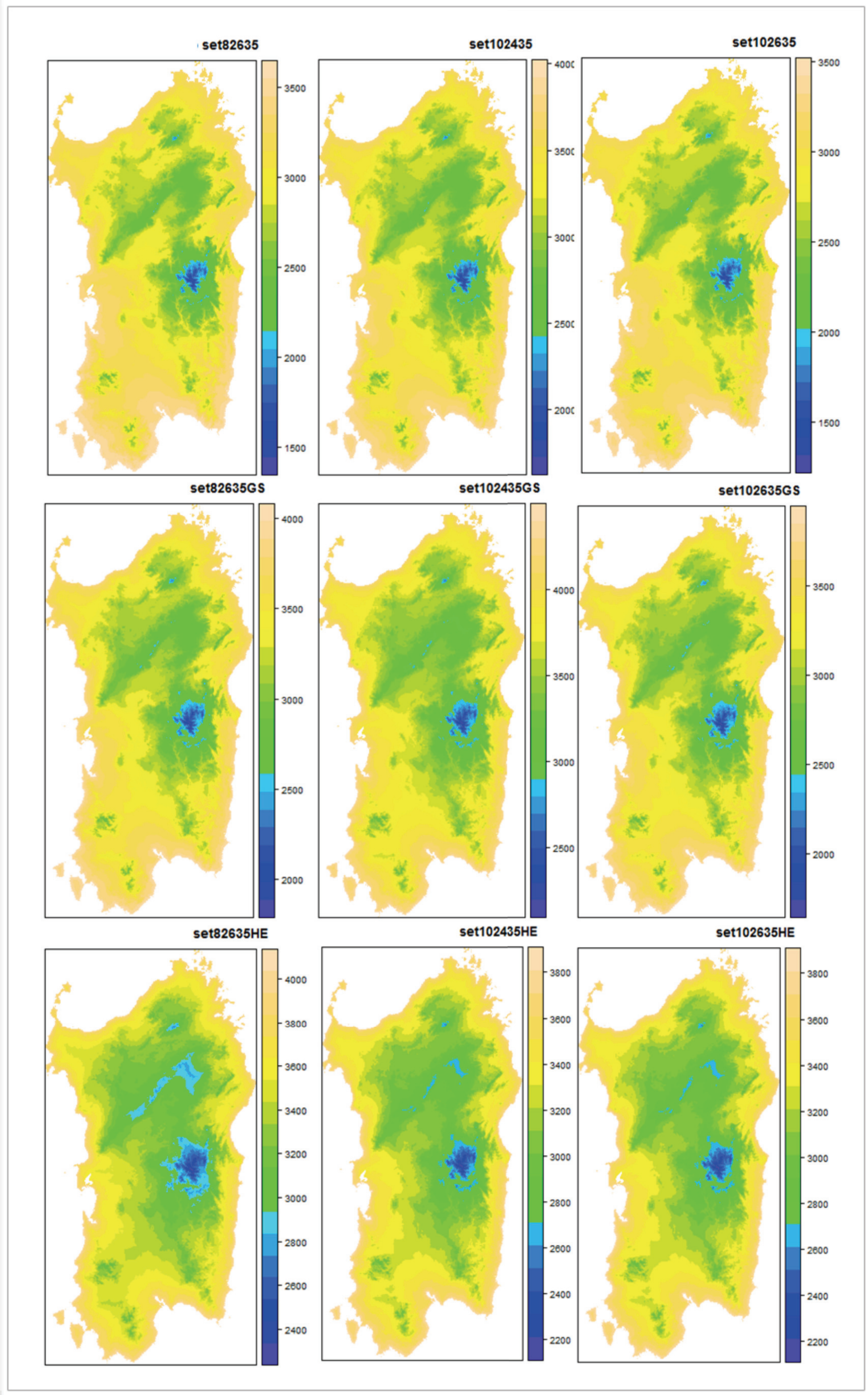


Figure 63 - Results for September NHH 8 26 35

In the figure for September, the 1971-2000 climate maps for NHH 8 26 35, 10, 24, 35 and 10, 26, 35.In the middle part of the figure are shown the maps of the GS model for the same thresholds. Below there are the projections of the HE model.

Considerations on the harvest of grape in October

Numerous wine-growing areas are located in the hills and in mountainous areas. In these places usually around the phenological cycle is shifted. It is possible at local level to use the calculated NHH thresholds to study the dynamics of late harvest.

The month of phenological advance is confirmed with all the thermal thresholds, as analyzed in September.

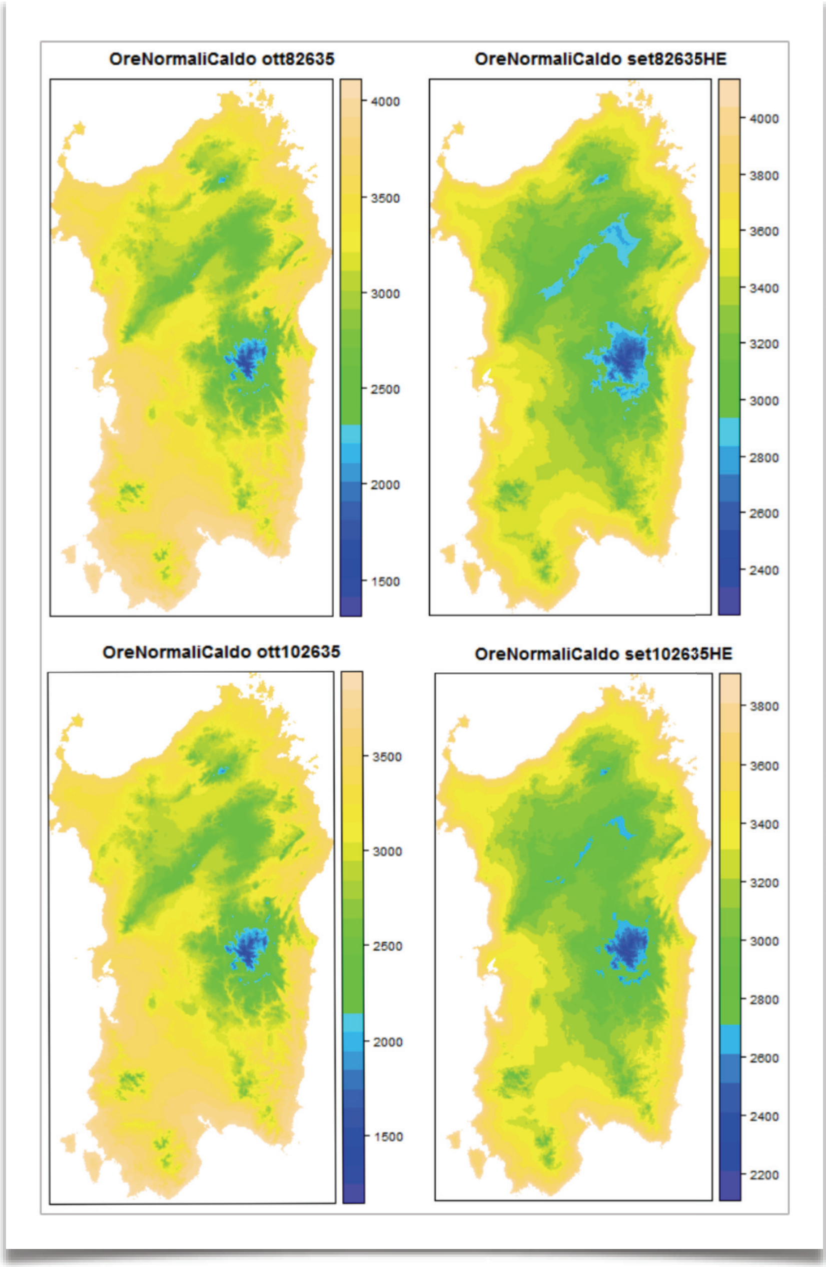


Figure 64 - NHH October 1971-2000 and HE model for Sardinia

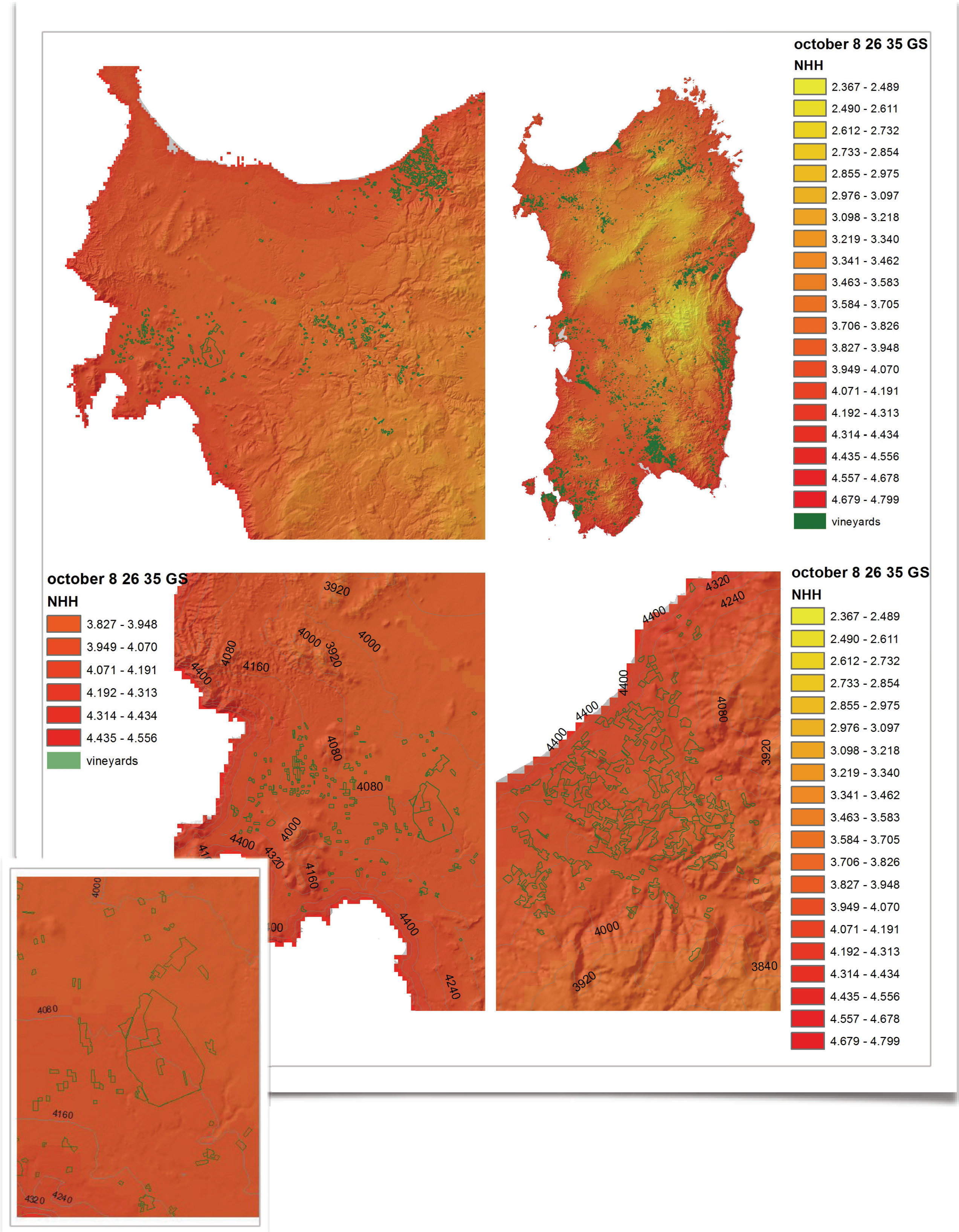


Figure 65 - NHH 2050 GS scenario. Sardinia - Nurra - Alghero - Sella and Mosca and Sorso

The GDD Huglin index applied to S. Giovanni Coghinas station, Ottava, Capocaccia and other weather stations for 1971-2010 show shows a significant growth trend of values for the annual value, always considering what is stated in the comment of figure 34 and in its paragraph of results about breakpoint and global trends.

In any case 2004 is climatologically considered one of the hottest years of the century and is evident from HI's thermal accumulation. In figure 66 the IH 19510-2010 for S.G. Coghinas.

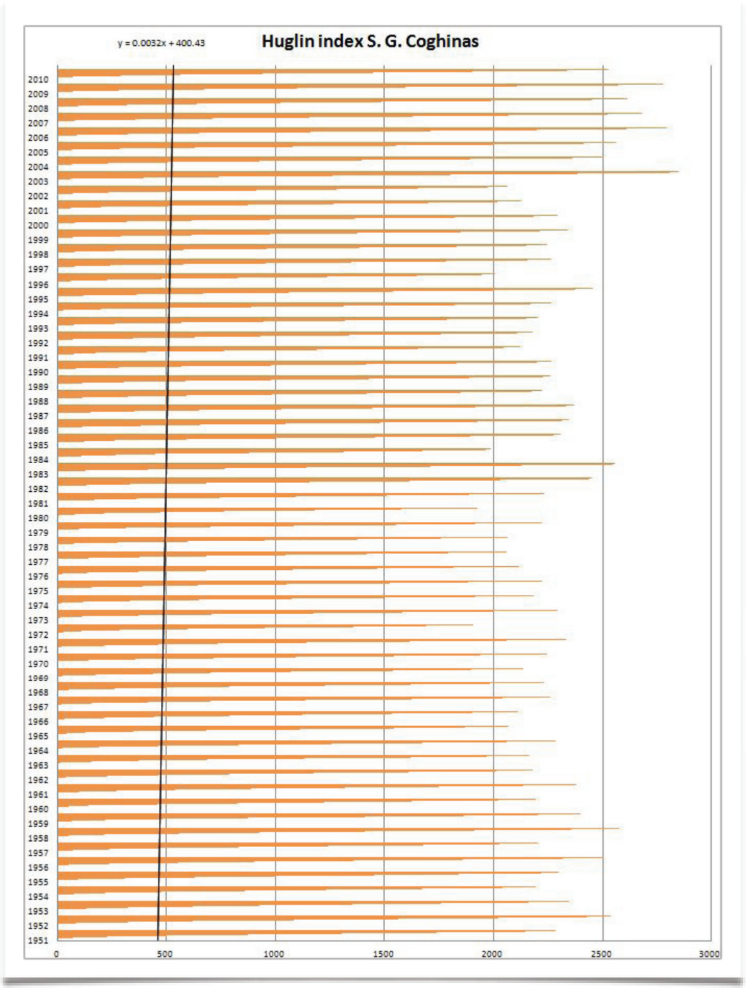


Figure 66 - Annual Huglin index trends of San Giovanni Coghinas station 1951-2010

In figure 66 the high increase in the Huglin index values obtained with climate scenarios for 2050 at the "station point" level.

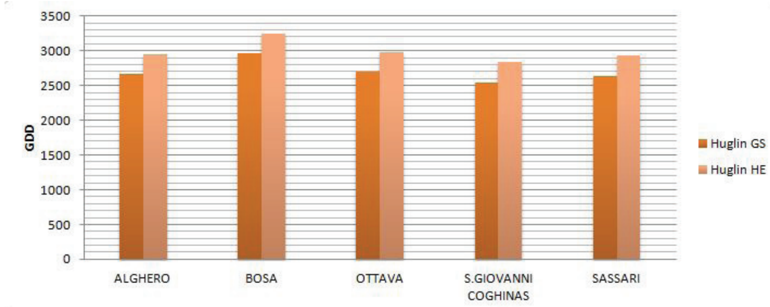


Figure 67 - 2050 Huglin index for Alghero, Bosa, S.G. Coghinas and Sassari

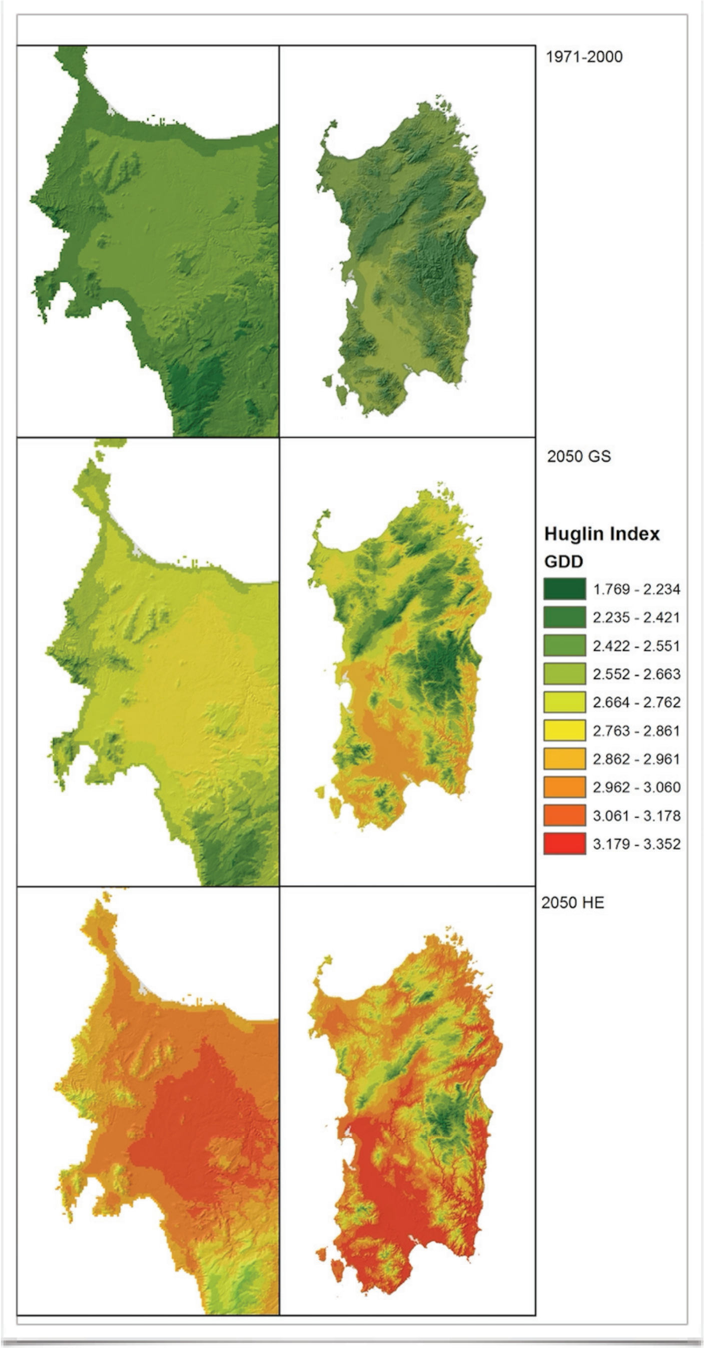


Figure 68 - 2050 Huglin index for Alghero, Bosa, S.G. Coghinas and Sassari

Figure 68 shows the increase in HI value from climatology to the application of the GS and HE scenarios. A unique color scale has been applied for all index levels in the six different maps, enabling to understand GDD differences. With the HE scenario the Nurra would reach GDD IH values between 2700 and 3100 and in Sardinia in the south, it would reach 3300 GDD.

The Fregoni quality index calculated at the "station point" level for the single station and the results obtained for objective 1 can not be used. It is a scalar index that starts counting over 10 ° C. This means that if a September day is 9.9 ° C the index of 0, as if there were 5 ° C, while with 10.1 ° C the index of 1. (Fregoni, 2003)

So it was calculated correctly at climatological level on maps for Objective III and not for the single meteorological stations for single days as reported.

For GS and HE scenarios, with the strong rise of the minimum temperatures in September the values of the Fregoni index are equal to 0, so they have not been calculated.

Consideration on HHH

We calculate 1971 - 2000 HHH for 8 26 35 and 10 26 35. The same thresholds with the scenarios GS and HE. The analysis offers numerous analysis cues. In Figure 69, 5 stations of Nurra are compared for 1971-2000 dataset: Bosa, S.G. Coghinas, Sassari, Ottava and Alghero. Calculation occurs only for temperatures above 26°C, above the optimum threshold. The largest thermal cumulus HHH occurs for the Bosa station, the most south and near the sea of Sardinia. Bosa station is, in fact, the first to obtain excessive heat over 26°C, since the beginning of June. The second to start is Ottava. In September the temperatures fall again below 26 ° C so there is no longer HHH and the values remain constant.

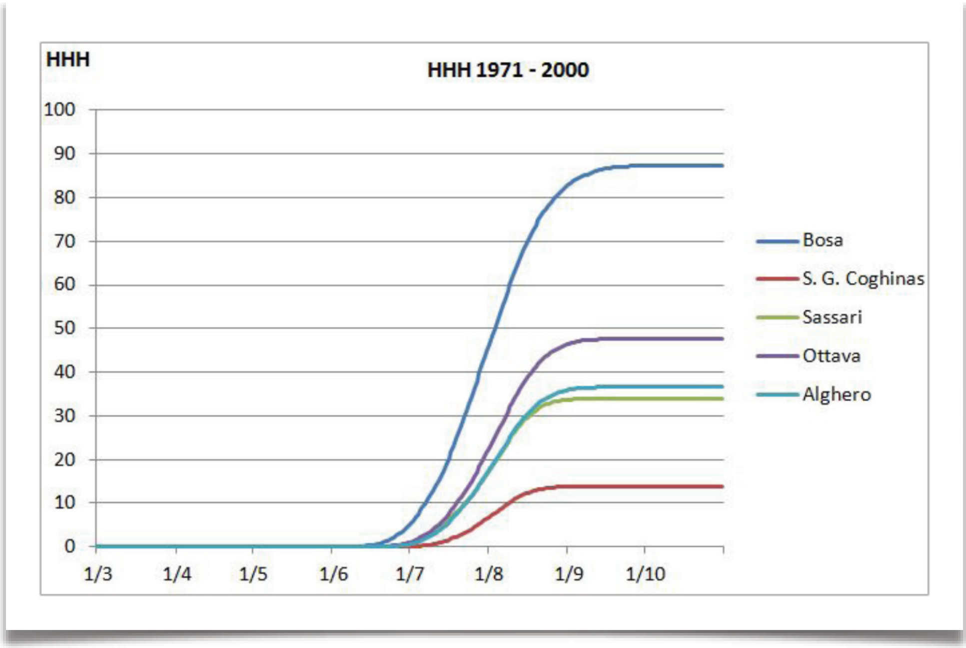


Figure 69 - HHH 8 26 35 for some 1971-2000 weather stations

In figure 69 for the same stations the HHH 2050 for HE scenario. It can be said that the thermal heaps with the scenario are five times larger. Bosa goes from just under 90 to just under 500. Additionally, HHH accumulations continue to grow until about mid-September, so they are longer. Thermal excesses allow it to better understand the effect of about 2 degrees more each day, and further weigh the phenological advance that they determine, as well as thermal stress on the vine.

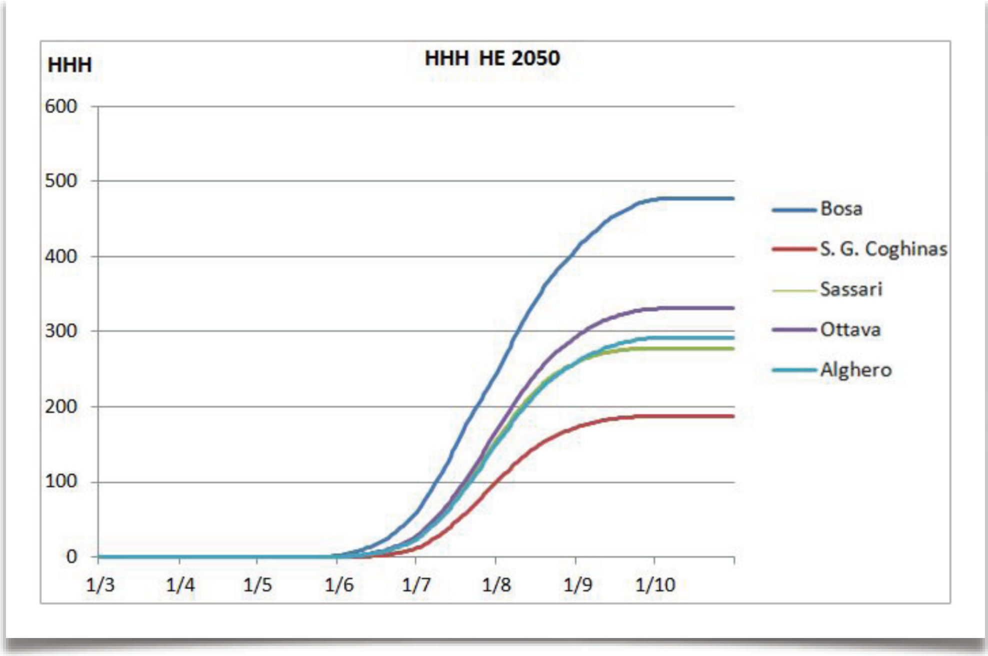


Figure 70 - HHH 8 26 35 for some HE 2050 weather stations

Conclusions

The present context of growth of studies on phenology as biomonitor of the climate change, where the modern phenology and the modern descriptor of thermal times are capable of reconstructing the development of the plants, makes the purpose of my thesis very current. We can say that the purpose of evaluating the effectiveness of the thermal time descriptor Normal Heat Hours, NHH, in a climate change context applied to the description of the viticultural systems from the point of view of the close relationship between thermal time and plant phenology has been achieved completely.

The quality of datasets information, the lack of relevant gaps in the historical dataset, the length of the time series, the ability to develop our own methodology using the full potential of modern computer systems and Geographic Information Systems and the availability of high-resolution climate scenarios, have been essential to accomplish the following results:

I) in relationship with the thesis objective **if there is a trend of temperature increase from 1951 to 2010 in Sardinia,** we obtained a strong trend of rising temperature between 1,5-2°C, in particular for the maximum and minimum temperatures. Historical research on data quality has been done that has led to work on few selected stations but with a high-quality assurance. The highlighted trend is even more important because of Sardinia's insular character, as the surrounding sea should reduce the increase of temperatures. Besides, the northwestern part of the island where our investigation focused the most, is affected by a strong cold mistral. (In the south west of Sardinia mistral becomes a warm wind, flying over the large stretches of land). The thermal increase verified, especially since the 1980, and the analysis of possible breakpoints, places work on Sardinia, as well as analysis in France, in a context of world climate studies.

II) Concerning the objective of understanding the impact of this potential climate change on viticulture through the application of NHH, an analysis has been done using hourly data together with available phenological data to assess if NHH could be used for understanding climate change. NHH models turned out to be quite robust and reliable in describing phenology. Arpas hourly data (1994-2010) allowed us to evaluate the needs of NHH Torbato, Cannonau and other early varieties such as Cabernet sauvignon. The thermal thresholds used in the bibliography have been verified and empirically tested. This allowed us to lay the foundations for the NHH 1971-2000 climatology calculation. This work was never done before, and a unique methodology has been developed with its own scripts. The result obtained was very satisfactory.

III) The work has been extended from single points to larger areas, in order to generate maps of the region of Sardinia by applying a suitable geo-statistical methodology using the Geographic Information Systems (GIS). The maps of meteorological data (ie temperatures, rainfalls) and agro-meteorological indices allowed us to understand how indices varied across the territory. To accomplish this goal it was essential to increase the current resolution of the maps and to get an appropriate resolution to take into account microclimate variability. In addition, NHH maps were generated for all selected reference thermal thresholds. Our study has not only been limited to the territory of Sardinia., but was extended to the Buzet site close to the Pirenees in France, replicating as far as possible the methodology adopted for Sardinia with the data of a single meteorological station, and thus showing the possibility of further extending this methodology to new latitudes and new series of phenological data. The calculation of NHH at a 24 °C threshold as the optimal spring temperature, as well as that of 22 °C for the sprouting period and 26 °C as the optimal summer temperature, is not only important for the calculation of the blossoming in April: the 26 °C threshold is applicable to the Olive, therefore a future development of this work will be to extend this methodology to the olive trees of Sardinia. The publication of the report *A general overview of the agrarian landscape of Sardinia, by* Department of Agriculture - Uniss and Region Sardinia, has shown how rural landscapes in many important regional contexts of Sardinia become vineyards landscapes, with a precise landscape identity.

IV)The fourth objective was to analyse, by applying the projected climate change, a range of scenarios in order to develop an understanding of what may happen in 2050 for the wine sector, and it has been successfully achieved. This allowed to reconstruct the state of viticulture in Sardinia from 1951 to 2050. Two different RCPs scenarios were applied, one with thermal increments of 1.6-2 °C and the other one with thermal increments of 2.6-4.3 °C.

It was found that, if new mitigation techniques for climate change are not implemented, the sprouting of the vine may take place as early as the end of January. BBCH 65 can occurs at the end of March. Harvest occurs for early varieties with 8°C of minimum temperature of development, such as Cabernet sauvignon, at the end of June or beginning of July, more than a month earlier. The harvest of Torbato and Cannonau, for example, which have a minimum temperature of development of 10 °C, may also happen a month earlier. With the HE scenarios, the most catastrophic and with some 4 °C thermal increases for several months, it is expected to have particularly high minimum temperatures close to 8-9 °C during the winter months. This could lead the vine to have an evergreen behaviour and could therefore modify the wine market.

It possible to express various considerations on vineyards landscapes in Sardinia.
The average area of Sardinia's farm is 0.7 hectares. The rural landscape of Sardinia is usually very fragmented. On the contrary, the studied territories, particularly the Alghero area, show that there are more than 1000 hectares of vineyards. More than 500 hectares belong to Sella and Mosca, an unique Wine Cellar, so it is correct to talk about vineyard landscapes.

The results are surprising. The scenarios maps could probably help to identify the more suitable wine-growing areas in the next future particularly in the north west of Sardinia.

Little single growers who belong to a cellar, like the typical owner of 5 hectares of the Santa Maria la Palma Winery Cellar, close to Sella and Mosca, may not have the resources to move their vineyards from the coastal strip to the interior, as as hypothesized in figure 71. Sella and Mosca are on the other hand capable of doing this. In fact, among the many possible economic scenarios, there is the possibility that vineyards located in coastal areas, instead of being re-planted on the site, are planted in hilly areas. A future development of this thesis will explore the economic scenarios of the rural areas under climate change, and try to simulate for example what will happen in the little “borgata” as Guardia Grande, in the Alghero - Santa Maria la Palma region.
The planning and planting of new vineyards in hilly areas could partly mitigate the phenological advance generated by climate change. Climate change could, in this view, be seen as an opportunity for a new and more responsible spatial planning.

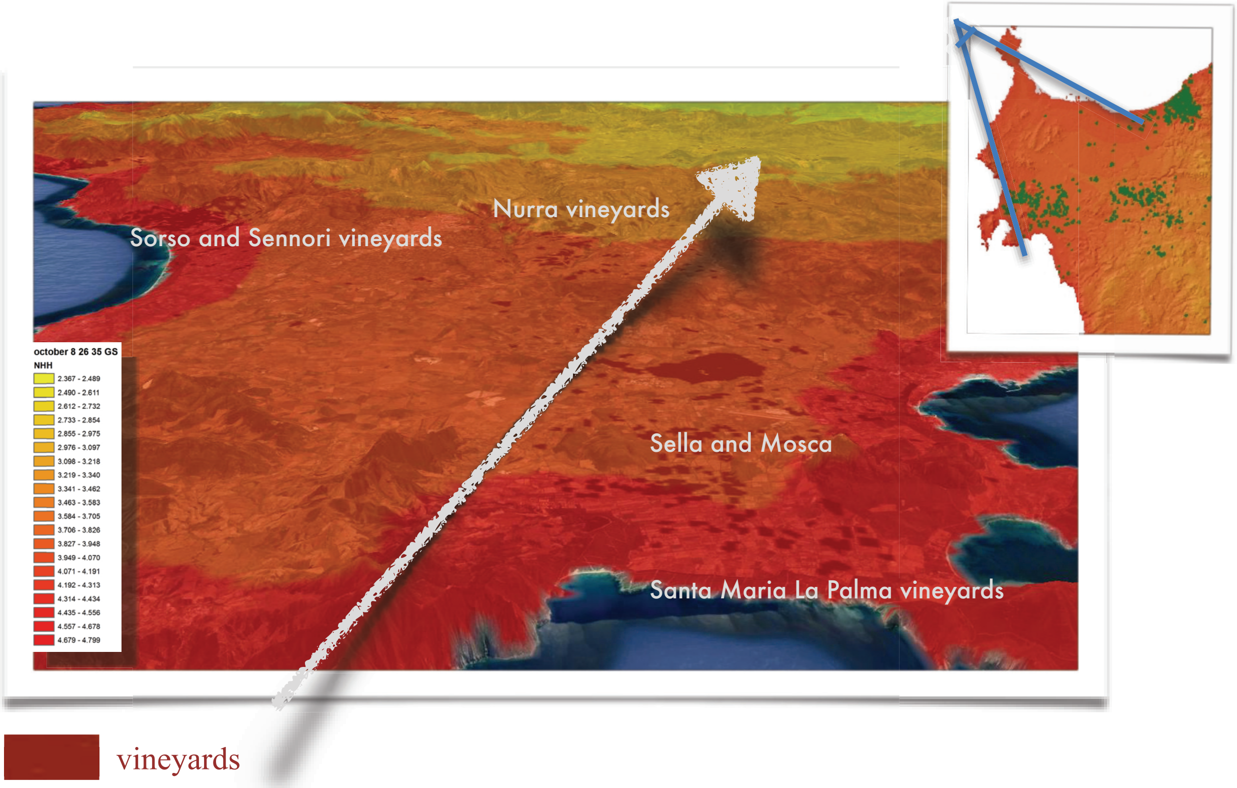


Figure 71 - Possible migrations of vineyards from the coastal area towards the interior

At the same time, wine growers may win the challenge of climate change with the help of technology. In this case, the current vineyard landscapes would be maintained thanks to an adaptation first, using genetic improvement (Mittler, 2010). While on the one hand the estimated precipitation reduction with climate change of about 20% does not particularly affect the production of the year, the thermal increase must be compensated to reduce the loss of synthesis of the aromatic components of the grapes. Grapes with genes for droughts and high temperatures resistance can be introduced. Agronomic mitigation techniques such as routing orientation, changing pruning periods can be adopted. The technical management of the vineyard could partially offset the change caused by climate change. Actually there are a lot of research projects that are working on it. Figure 72 shows the current orientation of the north-west rows in the small box and the possible east-west orientation for Sella and Mosca's case that could significantly reduce radiation and mitigate the effect of climate change.

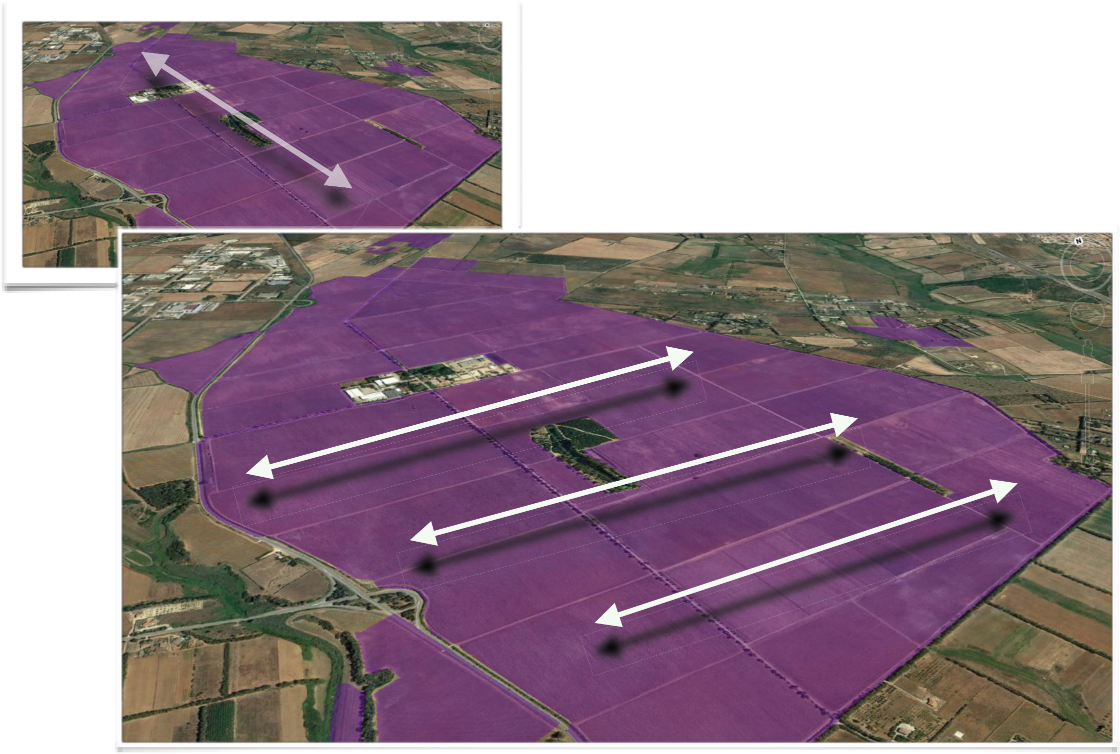


Figure 72 - The orientation as possible mitigation technic of climate change

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Appendix 1: NHH R code

R code used to calculate the NHH with different thresholds (in this case tc_min = 8 °C, t_opt = 26 °C, tc_max = 35 °C, but other combinations of critical and optimal temperatures were used). The hourly temperatures are obtained from daily maximum and minimum temperatures using the Parton and Logan's algorithm (1981) implemented in the R function "temp_hr".

In appendix 1 the most significative part of the R code used.

```
tc_min <- 8.
t_opt <- 26.
tc_max <- 35.

data <- read.table('dataset.dat',skip=3,dec='.')
lati <- as.numeric(data$V2)
tn <- as.numeric(data$V7)
tx <- as.numeric(data$V8)
cod<-as.character(data$V1)

tmin<-rep(NA,26718)
tmax<-rep(NA,26718)
lat<-rep(NA,26718)
nhh<-rep(NA,26718)
nhh_cumulata<-rep(NA,26718)
cod_staz<-rep(NA,26718)

t_hr<-rep(NA,641232)

dim(tmin)<-c(73,366)
dim(tmax)<-c(73,366)
dim(lat)<-c(73,366)
dim(nhh)<-c(73,366)
dim(nhh_cumulata)<-c(73,366)
dim(t_hr)<-c(24,73,366)
dim(cod_staz)<-c(73,366)
dim(nhh_cumulata)<-c(73,366)

#convert latitude from degrees to radians
gradi<-floor(lati/10000)
minuti<-floor((lati-gradi*10000)/100)
secondi<-floor(lati-gradi*10000-minuti*100)
gradi_dec=gradi+minuti/60.+secondi/3600.
latr <- gradi_dec*3.1415926/180.

for (st in 1:73){
for (day in 1:366){
    index <- (st-1)*366+day
    tmin[st,day] <- tn[index]
    tmax[st,day] <- tx[index]
    lat[st,day] <- latr[index]
    cod_staz[st,day] <- cod[index]
}}

# Parton & Logan model (Table 1, 150-cm air temperature):
a <- 1.86
b <- 2.2
c <- -0.17

temp_hr <- function(tmx,tmn,hr,a,b,c,nday,aphi)
{
# Simple adaptation of FORTRAN code from
# Parton & Logan
# "A model for diurnal variation in soil and air temperature"
# Agricultural Meteorology, 23 (1981), 205-216
#
# TMX = MAXIMUM TEMPERATURE
# TMN = MINIMUM TEMPERATURE
# T=TEMPERATURE AT THE SPECIFIED HOUR
# HR = HOUR FOR WHICH THE TEMPERATURE IS CALCULATED (0--24)
# A=TIME LAG IN MAXIMUM TEMPERATURE AFTER NOON (HR)
# B=COEFFICIENT THAT CONTROLS TEMPERATURE DECREASE AT NIGHT
# C=TIME LAG FOR THE MINIMUM TEMPERATURE AFTER SUNRISE (HR)
# NDAY----THE JULIAN DATE (1--366)
# APHI = LATITUDE (RADIANS)
# CALCULATE DAY LENGTH (ADY--HR) AND NIGHT LENGTH (ANI--HR)
#
adelt <- 0.4014*sin(6.283*(nday-77.)/366.)
tem1 <- 1.-(-tan(aphi)*(adelt))^2.
```

```
tem1 <- sqrt(tem1)
tem2 <- -tan(aphi)*tan(adelt)
ahou <- atan2(tem1,tem2)
ady <- (ahou/3.1415926)*24.
ani <- 24.-ady


# Calcolate Normal Heat Hours

alpha <- log(2.)/log((tc_max-tc_min)/(t_opt-tc_min))

for (st in 1:73){
for (day in 1:366){
nhh_i <- 0.0

for (hr in 1:24){
if (t_hr[hr,st,day] > tc_min & t_hr[hr,st,day] < tc_max) {
   nhh_i<-nhh_i+(2.*(t_hr[hr,st,day]-tc_min)^alpha*(t_opt-tc_min)^alpha-(t_hr[hr,st,day]-tc_min)^(2.*alpha))/
(t_opt-tc_min)^(2.*alpha)
}

nhh[st,day]<-nhh_i
}}}

for (st in 1:73){
nhh_cumulata[st,1] <- nhh[st,1]
for (day in 2:366){
   nhh_cumulata[st,day] <- nhh_cumulata[st,day-1]+nhh[st,day]
}}
```

Appendix 2: R code for geostatistical analysis

As attached the most significative part of the R geostatistics procedure used. In particular, the relationship with factors influencing spatialization is shown. Like latitude, quota, the sea distance. The procedure also produces statistical tests that evaluate the quality of the data obtained and report it to other possible combinations, for example by removing a station.

```
########################################################################


stazioni <- length(tmed010615$stazione)
stazioni                          # stampa su monitor
cor(tmed010615[,c("UTM_EST","UTM_NORD","QUOTA_SLM","dist_40_01","hr40_05","tmed")], use="complete.obs")
  library(MASS)
   mod.gen <- lm(tmed ~ QUOTA_SLM + hr40_05 + dist_40_01 + UTM_NORD + UTM_EST, data=tmed010615) # regressione
multilineare
mdQDNEH <- lm(tmed ~ QUOTA_SLM + hr40_05 + dist_40_01 + UTM_NORD + UTM_EST, data=tmed010615)
mdQDNE  <- lm(tmed ~ QUOTA_SLM + UTM_EST + dist_40_01 + UTM_NORD, data=tmed010615)
mdQDNH  <- lm(tmed ~ QUOTA_SLM + hr40_05 + dist_40_01 + UTM_NORD, data=tmed010615)
mdQDEH  <- lm(tmed ~ QUOTA_SLM + hr40_05 + dist_40_01 + UTM_EST, data=tmed010615)
mdQDH   <- lm(tmed ~ QUOTA_SLM + hr40_05 + dist_40_01, data=tmed010615)
mdQDN   <- lm(tmed ~ QUOTA_SLM + dist_40_01 + UTM_NORD, data=tmed010615)
mdQH    <- lm(tmed ~ QUOTA_SLM + hr40_05, data=tmed010615)
mdQD    <- lm(tmed ~ QUOTA_SLM + dist_40_01, data=tmed010615)
mdQ     <- lm(tmed ~ QUOTA_SLM, data=tmed010615)
################################################################### CROSS VALIDATION
# Influential Observations
# Influential Observations
# added variable plots
library(MASS)
library(car)
cutoff <- 4/((nrow(mtcars)-length(mdQDNEH$coefficients)-2))
plot(mdQDNEH, which=4, cook.levels=cutoff)
dev.off()
# Influence Plot
influencePlot(mdQDNEH,id.method="identify", main="Influence Plot", sub="Circle size is proportial to Cook's
Distance" )
qqPlot(mdQDNEH, main="QQ Plot")
dev.off()
library(MASS)
 sresid <- studres(mdQDNEH)
 hist(sresid, freq=FALSE, main="Distribution of Studentized Residuals")
 xfit<-seq(min(sresid),max(sresid),length=stazioni)
 yfit<-dnorm(xfit)
 lines(xfit, yfit)
dev.off()
# Evaluate homoscedasticity
 # non-constant error variance test
ncvTest(mdQDNEH)
# plot studentized residuals vs. fitted values
 spreadLevelPlot(mdQDNEH)
dev.off()
# Evaluate Nonlinearity
 # component + residual plot
 crPlots(mdQDNEH)
```

```
 # Ceres plots
 ceresPlots(mdQDNEH)
library(car)
vif(mdQDNEH)                      # Evaluate Collinearity - Variance Inflation Factors
viftmin <- vif(mdQDNEH)
# Test for Autocorrelated Errors
 durbinWatsonTest(mdQDNEH)
# Global test of model assumptions
 library(gvlma)
 gvmodel <- gvlma(mdQDNEH)
 summary(gvmodel)

  MODELLO step1(tmed010615)
                                  # cross validation
err <-0
err2 <-0
errAbs <-0

for (i in 1:stazioni) # in base al numero di dati
{
tmed010615.i <- tmed010615[-i,]
  md.i <- lm(reg, data=tmed010615.i)
  ypred.i <- predict(md.i,tmed010615[i,])
  err[i] <- (ypred.i - tmed010615$tmed[i])^2
        err2[i] <- (ypred.i - tmed010615$tmed[i])
      errAbs[i] <- ((ypred.i - tmed010615$tmed[i])^2)^0.5
```