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# **Adapatation of vIticulture to climate change: high resolution observations of adaptation scenarii for viticulture: The ADVICLIM European Project**

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**KEYWORDS.** Climate change, Fine scales, measurements, modeling, adaptation

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## ABSTRACT

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**ADVICLIM project aims at observing climate at local scales in different European vineyards, representing the climate diversity in European wine regions; simulating climate and climate change in order to produce a fine scale assessment of the climate change impacts, thereafter simulating scenarii of adaptation for viticulture. In order to demonstrate the importance of local management, the project will develop technologies which can be further applied to other agricultural territories in EU and worldwide; i.e. a network of agro-climatic measurements and a web platform that professionals will be able to access to visualize simulations of adaptation to climate change according to cultural practices as well as associated carbon footprints. It will combine field work, different modeling methods and information transfer to the wine industry and further agricultural organisms with the aims to providing information to help reflection on mitigation and adaptation strategies to climate change based upon local management of the environment and cultural practices as well as guidance to decision-makers in the viticultural sector.**

## 1. INTRODUCTION

Issues related to climate change increasingly concern the functioning of local scale geo-systems. A global change will necessarily affect local climates. In this context, the potential impacts of climate change lead to numerous interrogations concerning adaptation. Despite several studies on the impact of projected global warming in different regions, global atmospheric models (GCM) are not adapted at local scales and, as a result, impacts studies at local scales are still approximate. Although real progresses have been made in meso-scale atmospheric modeling over the past years, no operative model is yet in use to simulate climate at local scales (ten or so meters).

Current global change is affecting regional climates and hold implications for viticulture worldwide. Many studies have addressed the issue of the impact of climate change on viticulture in most of the wine regions worldwide, yet few studies are devoted to observing and simulating both climate and climate change at the "terroir" scale (local scale). However, phenological variations as well as difference in grapes/wine quality are often observed within short distances in a wine-region and are related to local characteristics (slope, soil, seasonal climate variation...). These local environmental variations are crucial in the specificity of a given location and need to be investigated systematically in order to be considered in the context of a rational policy of viticultural adaptation to climate change at local scale.

Since 2008, a team of multidisciplinary and international research on spatial analysis and climate modeling at terroir scales in the context of global climate change was put into place within the ANR-TERVICLIM and GICC-TERADCLIM programs. Using networks of agro-climatic measurements and different models (of climate, phenology and multi-agent systems), the impacts of climatic change were assessed at local scales in most of the viticultural climates worldwide (33 experimental vineyards located in 14 countries).

In continuation of these programs, the ADVICLIM-LIFE project aims to study in different European vineyards (representing the climate diversity in European wine regions) various scenarios of adaptation for viticulture at local scales. To achieve this objective, several levels of information will be collected from each vineyard: fine-scale climate data information and plant phenology, a description of different agricultural practices applied in these sectors, and finally information defining the socio-economic context of each vineyard.

This information will then be integrated into a multi-agent model able to take into account the interactions between those levels of information. One of the main objectives of the project is to develop both generic methodologies and models that can be applied to other agricultural territories. The final aim is to provide information to help reflection on adaptation strategies to climate change based upon local management of the environment and cultural practices as well as guidance to decision-makers in the viticultural sector.

## **2. OBSERVATION AND MODELING OF THE SPATIAL VARIABILITY OF CLIMATE AT FINE SCALES IN THE CONTEXT OF CLIMATE CHANGE.**

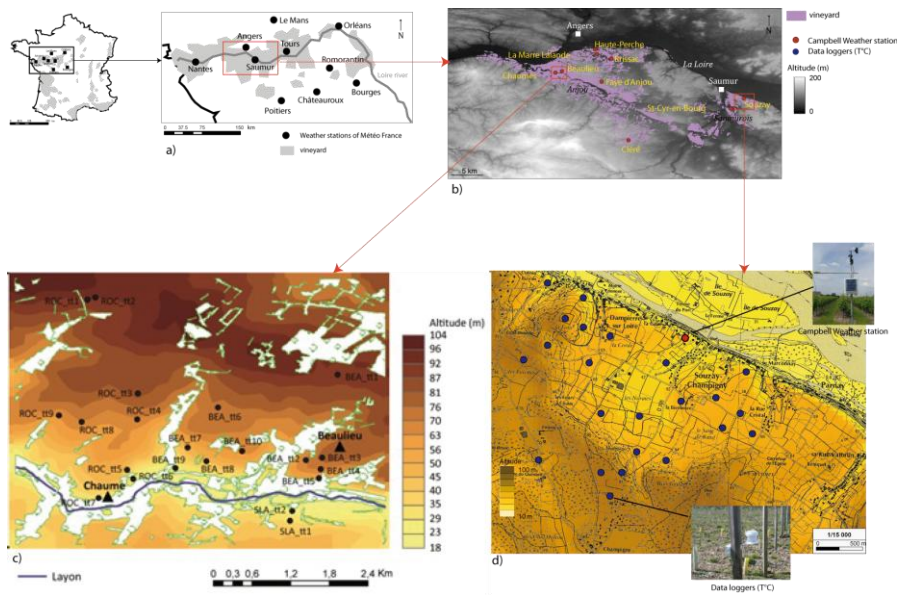
### **2.1 Observation of climate at fines scale**

National climate monitoring networks are frequently of insufficient spatial resolution to provide a clear picture of the temperature patterns in wine regions with a complex terrain. The originality of the ADVICLIM project lies in a unique network of thermal sensors and weather stations established since 2008 within the framework of the ANR-TERVICLIM<sup>a</sup> and GICC-TERADCLIM<sup>b</sup> programs. This fine scale network will provide valuable data to assess the spatial variability in each site, and to perform multi-criteria spatial modeling. Every experimental sites consist of an imbricated network of climate monitoring (see below the figure 1 for the example in the Loire Valley vineyards). The choice of the locations for temperature data loggers depends on topography (need to represent all parameters such as aspect, altitude, etc...); on soil types (need to represent the difference in soil texture, depth, etc.). Moreover, the number of temperature data loggers will depend on the environment (diverse or not) and the surface of the estate/district as it needs to cover it regularly.

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<sup>a</sup> « Observation et spatialisation du climat des terroirs viticoles dans un contexte de changement climatique » : ANR-JC07-194103 TERVICLIM (2008-2012)

<sup>b</sup> « Adaptation au changement climatique des terroirs viticoles. GICC TERADCLIM » dans le cadre du GICC-MEEDM (2011-2013)

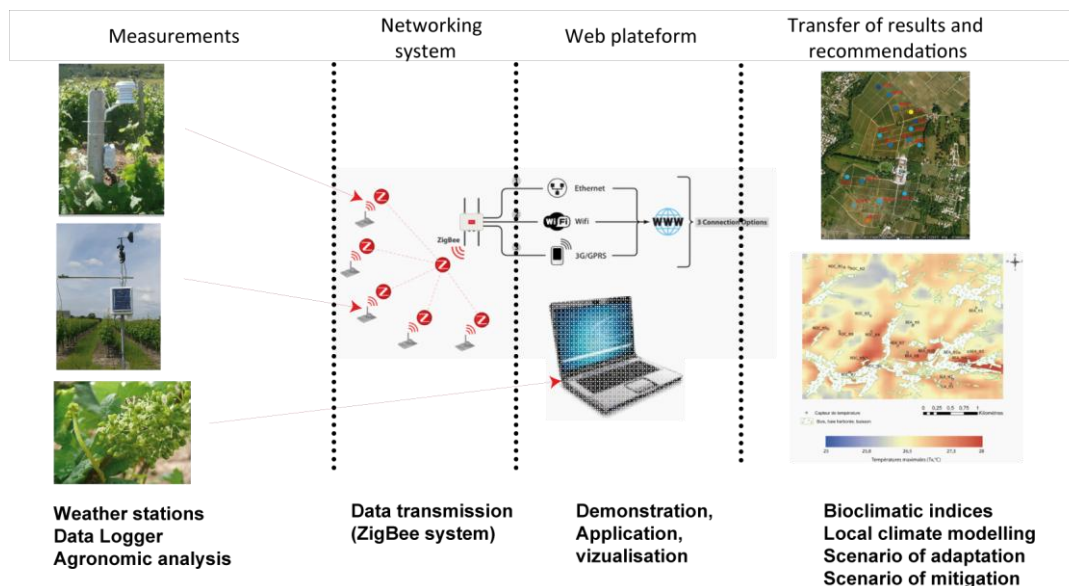


**Figure 1.** Weather stations and temperature data loggers in the vineyards of the Loire Valley.

a- At the regional scale of the Loire Valley Scale ; -b At the scale of the vineyard area of Anjou and Saumur; c- At the scale of the AOP Coteaux du Layon ; d- At the scale of the AOP Saumur Champigny

An electronic system of communication between the different data loggers and a website platform is required.

The thermal sensors (Data Loggers type) are located over a few square km surface in different wine producing regions worldwide. To date, these sensors are programmed and downloaded in the field with a laptop every month, resulting in important travelling costs and high consumption of time. The aim is to create a connection between each sensor (per site) in order to download real time data continuously via a Global System for Mobile Communications (GSM) and thus examine them via Internet (figure 2).



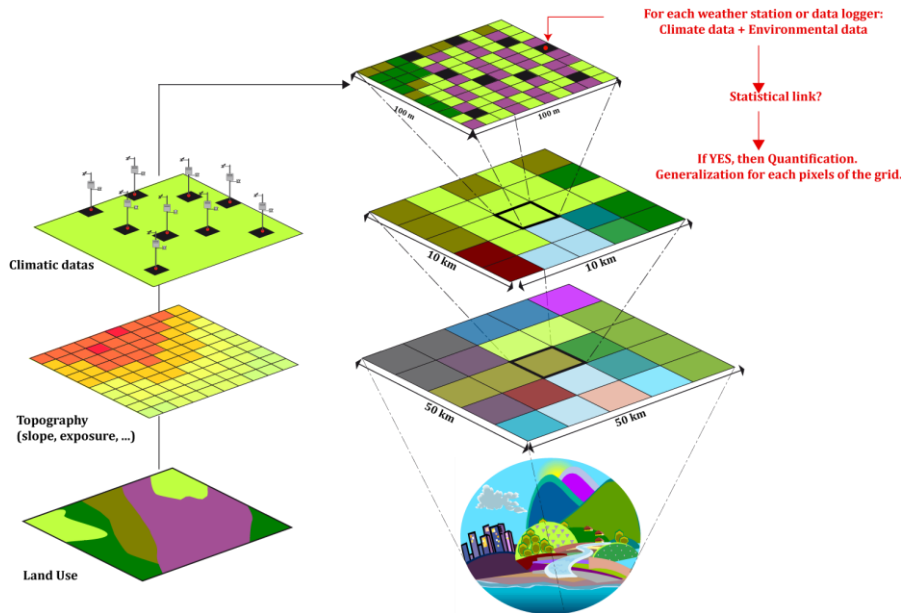
**Figure 2.** Agroclimatic data acquisition and visualization to wine and political organizations.

## 2.2 Modeling of climate variability at fine scales

Climate modeling at fine scales will include (i) the output from numerical regional models with a kilometer resolution (ii) the spatial modeling of climatic data from the measurement networks using multicriteria modeling at very high resolution (90m), and (iii) the future climate simulations using meso-scale climatic model ran under different scenarios of climate change.

(i) The coarse resolution output from numerical climate models requires downscaling. We use the downscaling output of regionalized model. It will provide knowledge and understanding of climate variability at meso-scale in the different studied European wine regions. Climatic data from national weather station networks will be used to validate the outputs of modelled data.

(ii) In order to construct fine-scale spatial temperature fields, the multicriteria modelling will be used. This approach takes environmental factors into account. Indeed, the role of topographic factors in the spatial variability of temperatures at fine scales, in addition to the influence of geographical location (latitude/longitude) at larger scale has already been demonstrated. This type of modeling will make use of the climatic data provided by the fine scale network (figure 3).

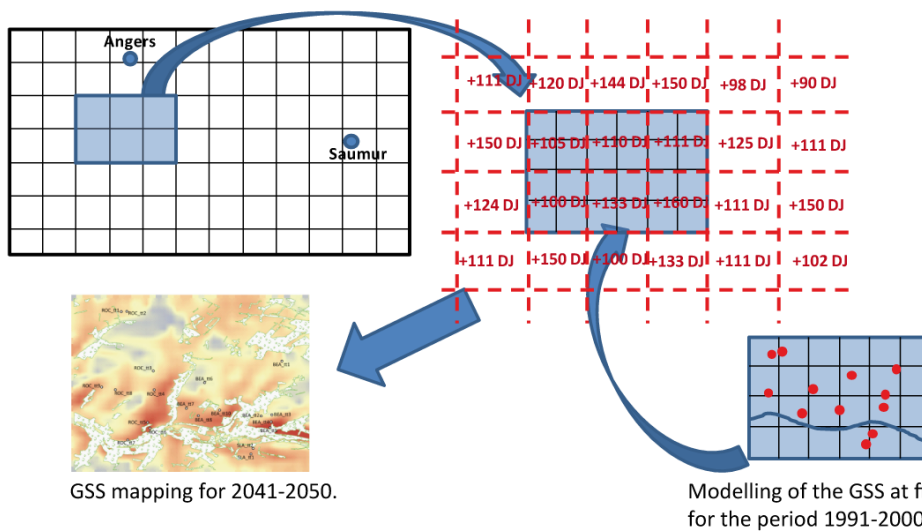


**Figure 3.** Spatial modeling of climatic data using multi-criteria modeling.

(iii) We use simulations of climate change scenarios (for Europe) carried out regionalized modeling program.

These data are integrated into statistical models. Combining the outputs of regionalized model with multi local models will allow performing simulations of bioclimatic indices for future conditions, such as for the period of 2041-2050 (Figure 4).

**Future climate data CORDEX (1km resolution)**  
*Evolution of the Growing Season Suitability (GSS)*  
 between 1991-2000 and 2041-2050



**Figure 4.** Simulation method (with downscaling) of climate data in the context of climate change (Bonnefoy, 2013).

Climate impacts local activities through two types of changes: (1) long-term slowly evolving mean and seasonal conditions; and (2) intensity and frequency of extreme events. The quality of grapes and the quantity of wine production are the results of these two scales of climate variability. While IPCC and regionalized model will certainly provide valuable information for changes of the first kind, it is highly probable that despite high-resolution regional simulations, extreme events may be only partially modeled. Therefore, in ADVICLIM, we consider it essential to provide scenarios of trends in extreme event risks, based on statistical methods. Present observations and modeling are sufficient to build statistical models relating atmospheric column characteristics with local risks of hail, frosts, heat waves, etc.

## **2.3 Phenological observation and modeling at fine scales**

Process-based phenological models for the grapevine work on the assumption that phenological development is mainly regulated by temperature. These models are driven by a temperature summation from a defined date and above a minimum temperature (threshold) until the appearance of a phenological stage (often judged at 50% level of appearance). Among phenological models for the grapevine, the Winkler Index [1] allows classifying vineyards worldwide into climatic zones. A different model was proposed by Huglin [2]. This author also published heat requirements for a set of grapevine varieties, allowing adjusting grapevine varieties to local climatic conditions. Although of interest, the limit of these two models is the fact that their construction was based on a limited dataset, collected in a limited number of sites. Recently, a new Grapevine Flowering Veraison Model (GFV) was published by Parker et al. (2011) [3]. This model is based on an extensive dataset (over 4,000 phenology observations collected in 123 sites) and advanced modelling techniques (PMP modelling platform [4]). It allows precise prediction of the timing of major phenological stages (flowering and veraison) for approximately one hundred cultivars of *Vitis vinifera* [5]. This model was validated at a regional scale with data collected in classic weather stations. In the ADVICLIM project, the GFV model will be tested at a very refined scale, inside winegrowing regions, with temperature data collected with Tinytalk sensors placed within the vineyards. To this purpose, phenological observations will be collected close to the temperature sensors.

These phenological observations include flowering, veraison and ripening. For grape ripening, grape samples will be taken weekly from veraison to ripeness. Sugar accumulation will be modelled as a function of local temperatures. The local use of the GFV model will allow the transformation of the temperature maps in spatialized predictions of the occurrence of phenological stages. It is likely that growers will have to change grapevine varieties in the future due to changing climatic conditions [6; 7]. The phenology maps, coupled to established heat requirements for grapevine varieties, will allow growers to optimize the adjustment of varieties to local climatic conditions.



### **3. ADAPTATION OF CULTURAL PRACTICES TO CLIMATE CHANGE**

Using of a multi-agent model in contrasted situations: developed within the framework of the TERADCLIM program, the DAHU-Vigne simulation platform uses geomatics-based technologies, object-oriented models and spatiotemporal databases. The approach is based on a multi-agent modelling environment able to simulate vine growth under multiple constraints (slope, orientation, type of soils, climatic variability...) and to integrate production strategies as well as regulations to adapt such strategies according to these constraints' evolution. The approach proposed aims to connect field observations [8] to issues in terms of seeking optimal vine adaptation to wine-producing soils' specificity [9; 10]. This issue is fuelled with multiple field data (knowledge base referring to the vine-related set of biophysical data and agronomic parameters). However, production strategies are not as well known, as they refer to individual experiences that are particularly difficult to model. Hence, the model's main challenge is to complete the modelling of decision-making chains resulting in the various vine management methods observed in the field.

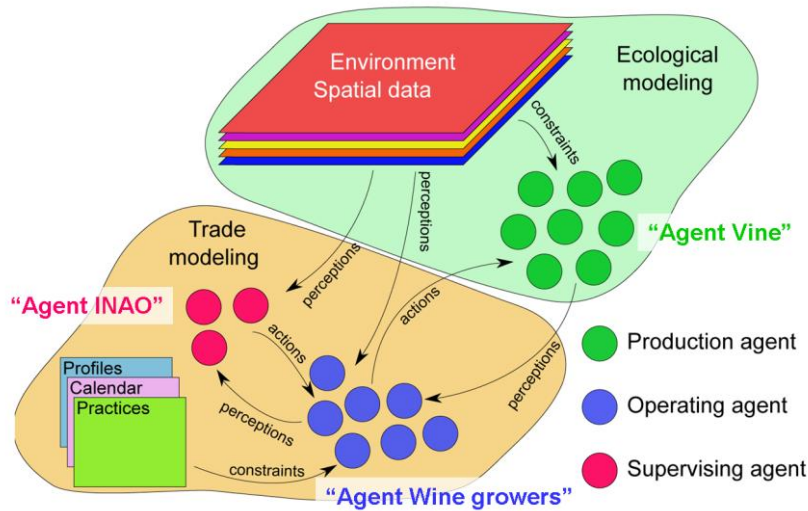
In the DAHU-Vigne simulator, the approach will be developed in order to optimise the connections between "supervising", "operating" and "production" agents:

- the "supervising" Agent plays a supervising role in the model. It sets the specifications of the various wine designations and imposes specific production methods. It is directly related to the "operating" Agents that provide it with information regarding the quality of grapes produced by their vines. According to this information, the "supervising" agent may modify these specifications;

- "operating" Agents aim to produce wine complying with precise specifications according to the target designation. This action involves growing the vine in optimal conditions taking into account the agronomic specificities of the vine-grower's plots;

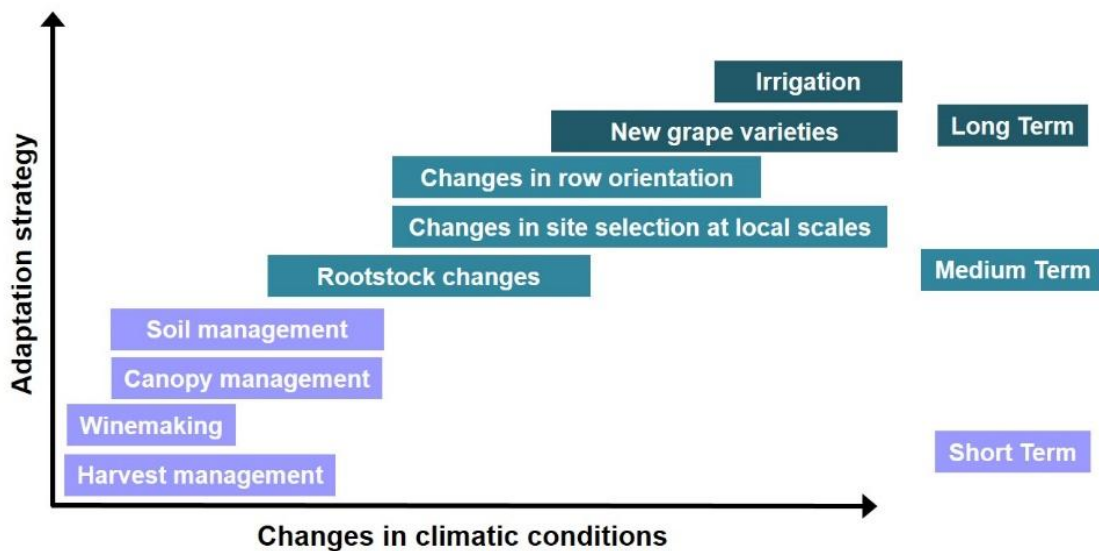
- "production" Agents are grape production entities. They generally represent a plot or an entity deemed homogeneous in terms of agronomic features (definition based on soil units [11]). The role of these agents is to reproduce vine growth dynamics according to local climatic conditions.

The relationships between these three types of agents determine the production strategies adopted by the vine-growers. The Operating Agent group was thereby enhanced with decision-making regulations established from a base of regulations under climatic constraints (figure 5).



**Figure 5.** Global structure of the DAHU-Vigne simulator.

The multi-agent model will be thus the linking between the results from the cultural practices implemented by wine growers in the different experimental vineyard sites of ADVICLIM. In-depth surveys are carried out with wine professionals (winegrowers, engineers...) in order to integrate crop and working calendars specific to each European wine region and to assess the means and capacity to adapt to climate change. These surveys provide a typology of adaptation methods to climate change according to different time scales (short, medium and long term) and according to the European wine growing regions. This type of survey has been used by UVV-INRA Angers to interview winegrowers of the Loire Valley (figure 6). The results of these surveys are included in the DAHU-Vigne model in order to perform various scenarios of adaptation to climate change for each experimental vineyard.



**Figure 6.** Adaptation strategy in Loire Valley (Neethling et al, 2013)

#### 4. DEMONSTRATION ON EUROPEAN PILOT SITES

Several experimental vineyards are necessary because they represent all European wine macroclimates, in certain areas the impact of Climate Change is negative (Mediterranean region) or positive (Northern Europe) that can generate favorable future conditions for the culture of vine growth.

Different scenarios of adaptation will be developed on 5 European countries, which will provide a representative model of the entire European viticulture in diverse environmental situations (please see pilot sites location map in appendix and table pilots sites per bioclimate situation in figure 7), the pilot sites is essential to achieve the objectives of the project and especially to obtain a real added value for Europe by testing the efficiency of our methodologies and outputs for viticulture at European scale.

The experimental sites are chosen to ensure representing the diversity of actual climates in Europe, as well as future climates according to the different climate change scenarios. ADVICLIM does not cover all European environmental situations but the location of pilot sites is diverse enough to develop a reproducible methodology at European scale (please see annex 1 in attached file):

- In France (oceanic/temperate climate)

Vineyards of the Loire Valley (Coteaux du Layon and Saumur) and Bordeaux (St. Emilion) experience optimal conditions under current climate with some regional variations especially for the most northern vineyards. Simulations of other bioclimatic indices characterizing drought levels and rainfall resulted in optimum conditions that will decrease in these regions towards the end of the century.

- In Germany (temperate/semi continental climate)

Geisenheim corresponds to the most northern European vineyard (50° northern latitude). This steep slope viticultural area with the presence of the Rhine River allow favorable conditions for grapevine cultivation despite heat losses related to the latitudinal position. According to future climatic simulations, thermal conditions will be optimal.

- In Romania (continental climate)

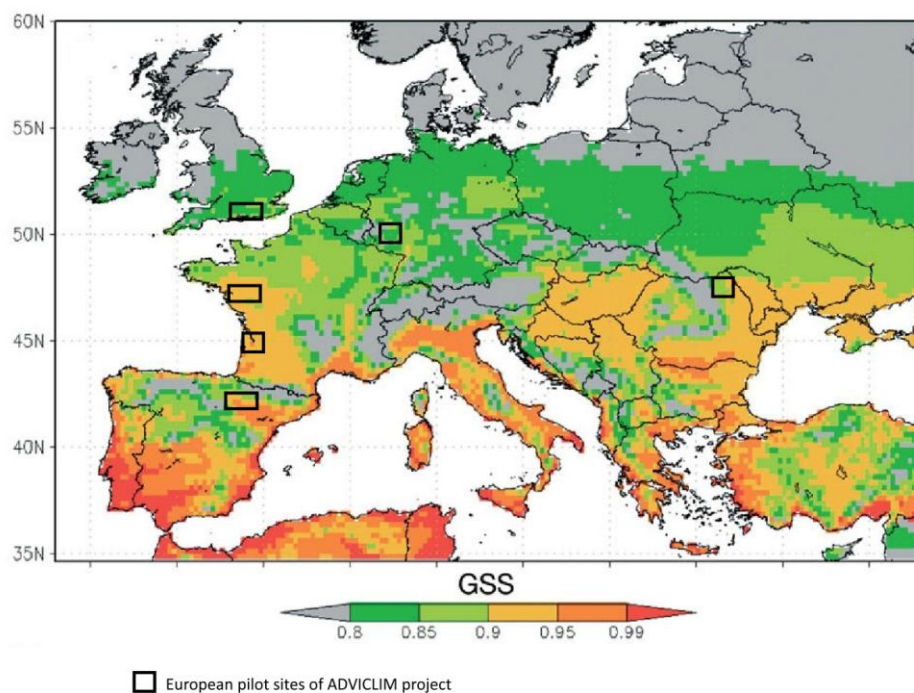
Vineyards of Cotnari in Romania are the most Eastern European vineyards. Present thermal conditions are not very favorable for viticulture with frequent occurrences of extreme climatic conditions. Simulations of future climates show that thermal conditions will become more favorable than compared to current conditions, although extreme heat events are expected to occur more frequently.

- In United Kingdom, (cool climate)

Vineyards in the UK operate at the northern extremes of commercially viable viticulture and the industry has production challenges linked to its cool climate conditions and youthful status as a quality wine-producing country. Despite this, the UK wine production industry expanded rapidly from under 800ha in 2005 to over 1300ha in 2012, and continues to grow. The wines produced are aimed at the premium market at the pricepoints occupied by good wines from Champagne.

- In Spain (Mediterranean climate)

Vineyards in southern Navarra in Spain are grown under semiarid climatic conditions (mostly Class HI+1, Warm, according to Huglin's scale), and irrigation management is necessary in order to maintain summer grapevine stress under adequate levels. Simulations of future climates show thermal conditions to become even more unfavorable, with lower rainfall levels, increasing drought conditions; and extreme heat events are expected to occur more frequently.



**Figure 7:** Mean pattern of the growing season suitability\* and location of ADVICLIM pilot sites (Santos et al, 2012). \* Growing season suitability (GSS), fraction of days in April September with daily mean air temperature equal to or above 10°C.

## 5. INFORMATION TRANSFER TO THE VITICULTURAL SECTOR

ADVICLIM project has a main objective to make the transfer between the "research and development" towards the applications (shift from "laboratory" to the application) that will allow to change the behaviour of wine professionals and policies.

Our objective is to allow the project researchers and stakeholders to have access to a large set of project data (meteorological stations, satellite data, model outputs, carbon footprint results, etc...) for research as well as to respond to the needs of the actors (viticultrual sector, public organizations, political ...) in order to easily release information to the viticultrual sector and raise their awareness of climate change.

Considering the diversity of data sources, the diversity of the needs (extraction for research, visualization for decision-making as well as diffusion and communication for awareness campaigns), we will first define with researchers and stakeholders the specific functionalities expected by the different users. We will structure the VIDAC (VID Data Archive Center and Visualization Platform) in four different layers:

- Layer 1: Data storage

In the Layer, we will store all data requested by the project researchers and stakeholders as well as data produced by the project. The data storage will be organized using a metadatabase.

- Layer 2: Model and algorithms

In Layer 2, we will apply different quality control methods and algorithm to prepare data for extraction or visualization

- Layer 3: Data access and visualization

In Layer 3, we will provide interfaces for data selection and extraction according to researcher requests

- Layer 4: Web interface for the viticulture sector

In Layer 4, we will develop an operational user-friendly interface for the viticulture actors involved in the project. The interface will allow them to visualize station data collected in their fields as well as other relevant data for their decision-making process. Future climate scenarios and carbon footprint results will also be considered as possible modules to be added during the project to promote awareness on climate change issues. The VIDAC Platform will be built on the experience acquired in the FP7 CLARIS LPB Project ([www.claris-eu.org](http://www.claris-eu.org)) where a CLARIS Data Archive Center was designed and developed to help the researchers to access model and observed data for research (see Figure 12a-b-c). It will also integrate specific developments made and commercialized by ECOCLIMASOL for the agriculture sector under the brand ClimaVista® Agro. Some of the ClimaVista® Agro platform will be adapted to the specific needs defined by the ADVICLIM project and will offer valuable information for the viticulture stakeholders involved in the project (see Figure 8).



**Figure 8:** ClimaVista® Agro Platform developed and commercialized by ECOCLIMASOL. This platform allows to visualizing specific meteorological and satellite data at the terroir scale. The platform will be transferred and adapted to the ADVICLIM requirements and will allow the project stakeholders to have access to the fine scale meteorological stations installed in their domains.

## 6. CONCLUSION

The main impact of the project concerns the implementation of adaptation method for agriculture (mainly perennial crops) to climate change. This multidisciplinary methodology is based on the analysis and modeling of spatial climate variability at local scales. ADVICLIM has the objective to provide adaptation models to climate change based on data observed at local scales. This allows to limit the large uncertainties related to global and regional climate models. As indicated by Le Treut (2010) "despite the convergence of models to widely shared results and who seems to be meaningful at large scales, two types of uncertainties remain, corresponding both to the magnitude and to the location (in time or in space) of the expected effects. It is still impossible to answer specific questions such as: what will be the most important local impacts and how to protect them? [...] A better prediction of local climate changes is therefore a key issue to address and adapt to changes, part of which is inevitable". ADVICLIM will provide concrete data on the spatial variability of climate in European vineyards that are characterized by specific macro-climates (Mediterranean, oceanic, temperate and continental). These observed data combined with the outputs of regionalized climate change models (Euro-Cordex) will permit to define different adaptation scenarios for European perennial crops.

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