MACSUR Project
The case study of vineyards.

Eco-physiological and biophysical modeling applied to the growth and productivity of vineyards in northwestern Italy

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The integrated project

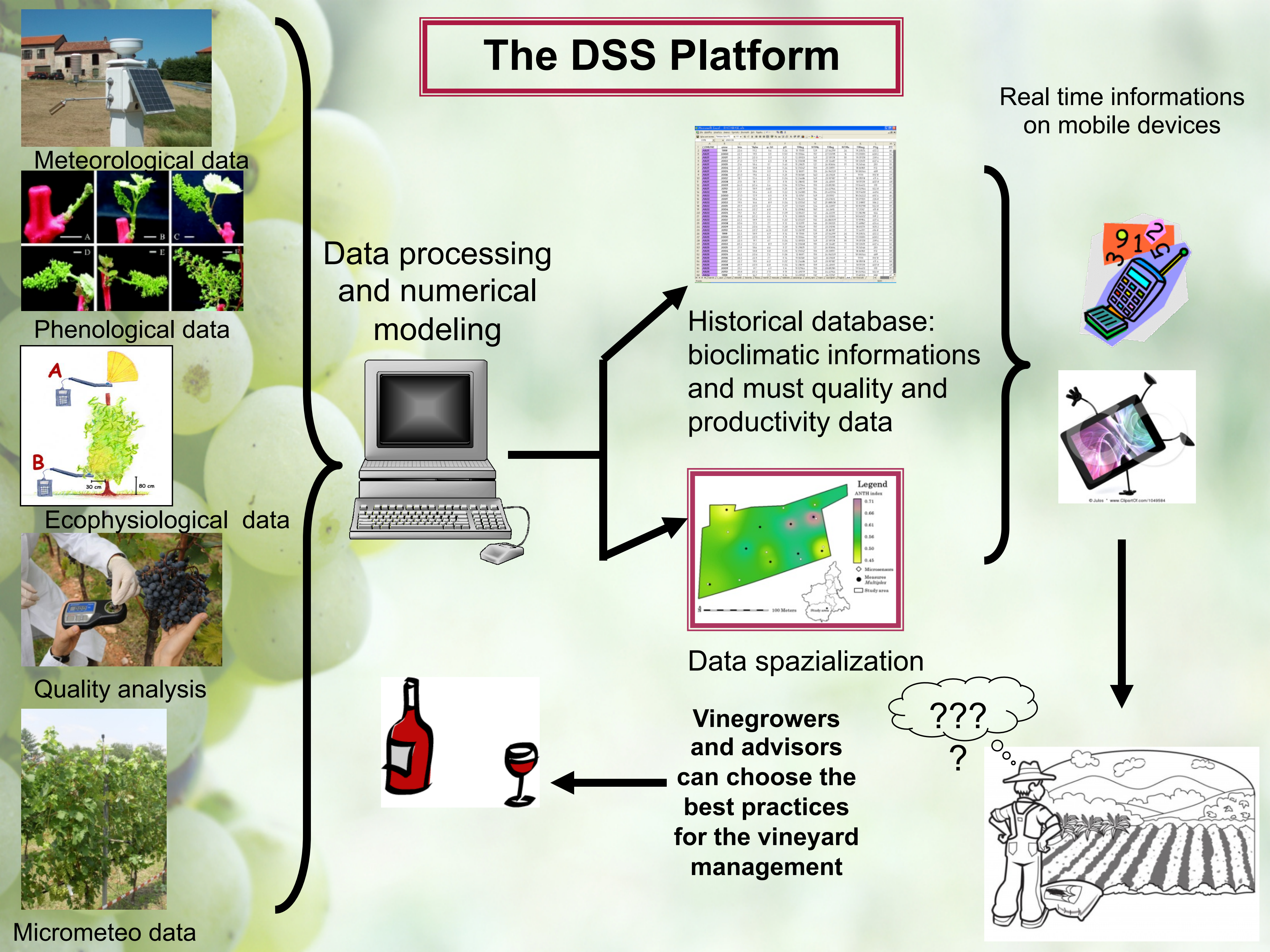
Adoption of a multidisciplinary approach to study the grapevine agro-ecosystem: analysis of biotic and abiotic factors able to influence yield and quality of wine

Development of instruments and knowledge for vineyard management and wine quality improvement

Project Phases

- Field experimental activity
- Numerical modeling

- Agrometeorologists
- Physiologists
- Physicists
- Entomologists
- Phytopathologists
- Chemicals
- Wine producers and companies



The DSS Platform
Meteorological data
Phenological data
Ecophysiological data
A
B
30 cm
80 cm
Quality analysis
Micrometeo data
Data processing and numerical modeling
Historical database: bioclimatic informations and must quality and productivity data
Legend
Data spazialization
Real time informations on mobile devices
???
?
Vinegrowers and advisors can choose the best practices for the vineyard management

STEPS OF THE INTEGRATED PROJECT

1 → Realization of an historical database (climatic and bioclimatic data, ecophysiological informations, grape quality and productivity)

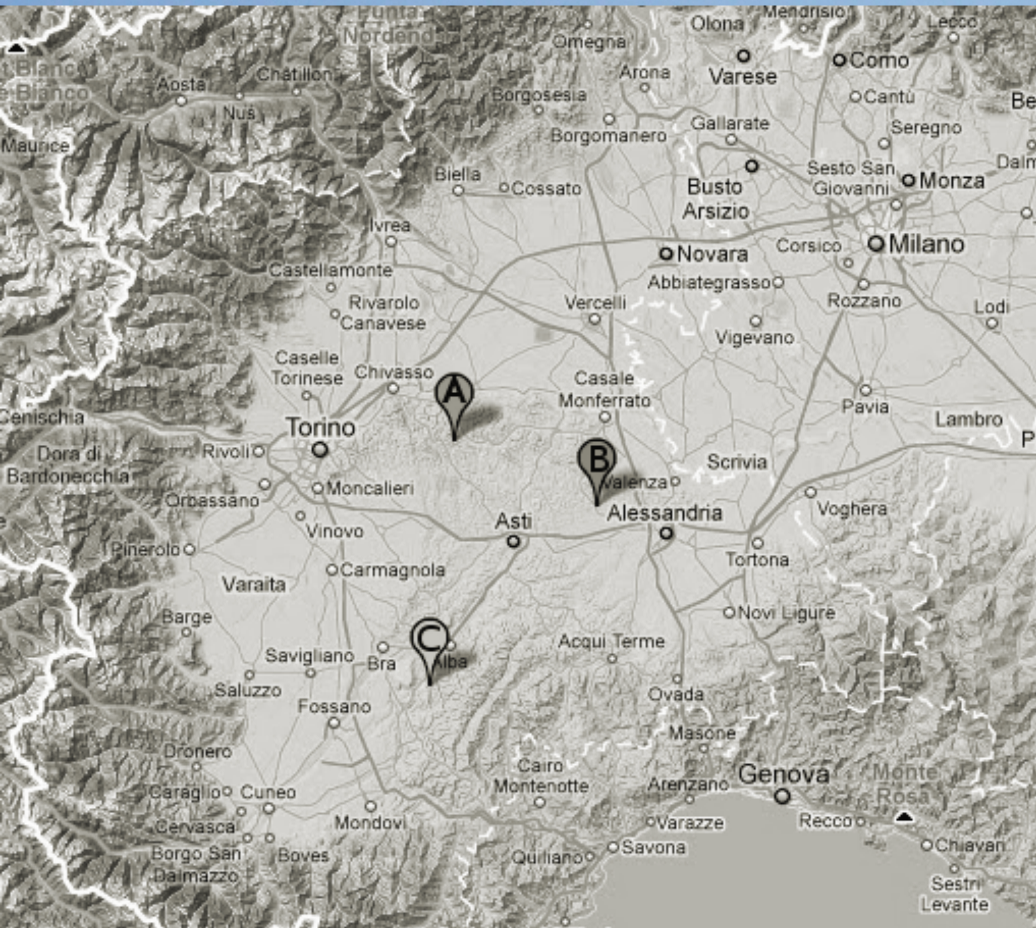
2 → Field experimental activities

3 → Model evaluation, calibration and application

Biophysical approach

Ecophysiological approach

The field experimental activity



Growing seasons 2008-2013

Experimental measurements carried out in several vineyards

Varieties: Nebbiolo and Barbera

Regions: Monferrato and Langhe

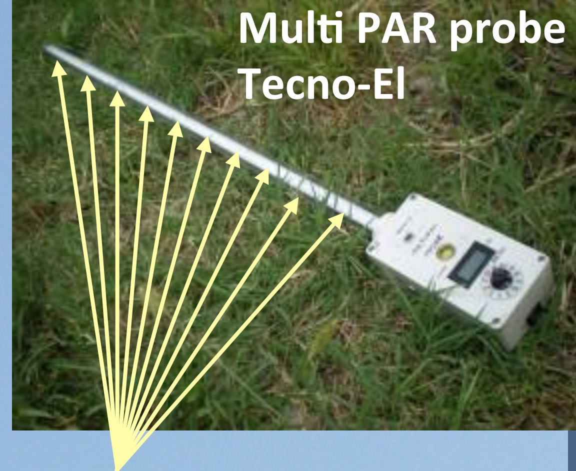
Directly measured variables:

CONTINUOUSLY
- Air temperature and humidity
- PAR (Photosynthetically active radiation)
- Wind speed and direction
- Soil temperature and humidity
- Net radiation

BIMONTHLY
- Physiological variables (dry matter)
- Point gaseous exchanges
- LAI

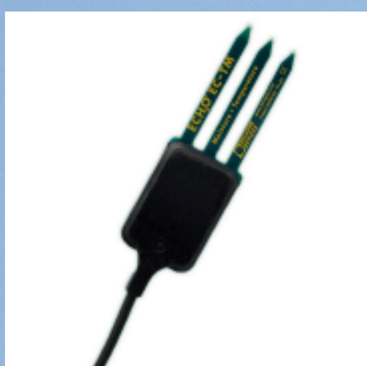
- Grape quality parameters
- Vine productivity parameters

Experimental setup



$$\frac{R_{\text{int}}}{R_{inc}} = 1 - e^{-LAIk}$$

ECH2O EC-TM Decagon



Data from:

Agrometeorological network, Regione Piemonte

Experimental setup

Fast response sensors – Eddy Covariance

Ultrasonic anemometer

Corrections for:

- Too high temperatures
- Tilted positioning with respect to the active surface

2008–2010
cv Barbera

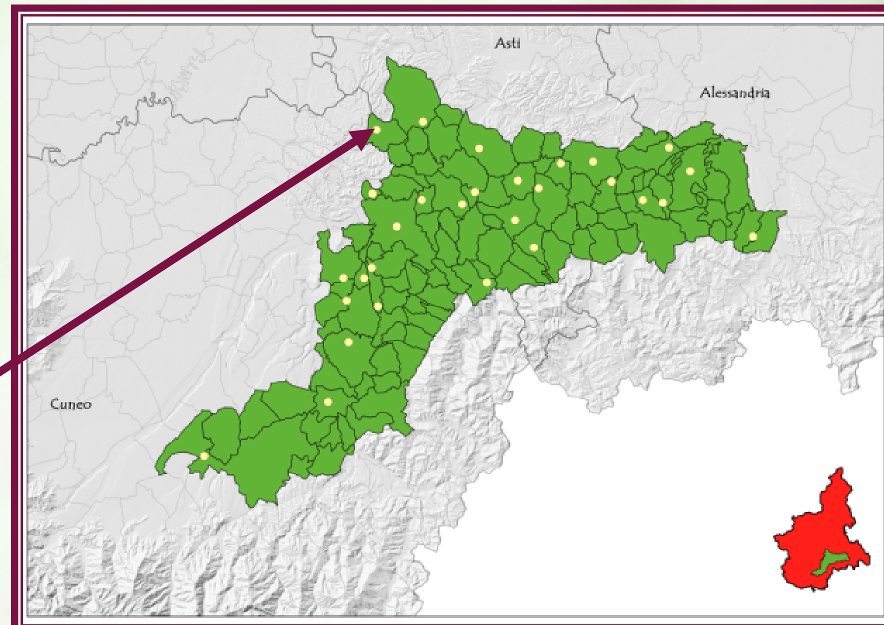
1 → Historical database (climatic data ,bioclimatic indices, grape quality and vine parameters)

Cultivar considered

Cultivar	No. of vineyards	No. of meteorological stations
Arneis	9	5
Nebbiolo	30	12
Barbera	7	7
Cabernet sauvignon	2	2
Chardonnay	6	6
Dolcetto	13	9
Favorita	2	2
Freisa	2	2
Merlot	2	2
Moscato	46	19
Pelaverga	2	1
Pinot nero	3	3
Sauvignon	3	2

For climatological analysis data were provided by 28 electronic stations, belonging to the Regional agrometeorological network (RAM) located within 5 km from the vineyards, in Alessandria, Asti and Cuneo Provinces

Area investigated and localization of meteorological stations



Historical dataset

Data from 1999 to 2013

Grape Quality Indices

MOSCATO GRAPE									
Weight of 100 raisins	pH	total acidity	titratable acid	total soluble solids	alcool pot	linalolo	ossido C	diendiolo 1
g		g/l	g/l	° Brix	% vol.	ug/l	ug/l	ug/l

NEBBIOLO e BARBERA GRAPES								
Average raisins weight (g)	pH	total acidity (g/L)	° Brix	A3.2 (mg/L)	A1 (mg/L)	EA%	A280	Mp% (RTA=77)

A1 = potential anthocyanins; A3.2 = potential extractable anthocyanins; A280 = total poliphenols index
EA% = indiex di maturità cellulare; Mp% = tannins conibution

Bioclimatic Indices :

	VARIABLE
TMng	MINIMUM DAILY TEMPERATURE (°C)
NTMn	DAYS WITH MINIMUM TEMP. < O AND =15 °C
TMxg	MAXIMUM DAILY TEMPERATURE (°C)
NTMx	DAYS WITH MAXIMUM TEMP. > O AND = 35 °C
TMmg	MEDIUM DAILY TEMPERATURE (°C)
PGg o SPU	TOTAL PRECIPITATIONS (mm)
P>1 o NGP	NUMBER OF RAINY DAYS
ST10 o STA	THERMAL SUM (°C)
HUGLIN	HUGLIN INDEX (°C)

ESCURS o SET	THERMAL EXCURSION SUM (°C)
RAD	TOTAL SOLAR RADIATION [MJ/m2];
PAR	PHOTOSINTETIC ACTIVE RADIATION [MJ/m2]
NHH_giorn	NORMALI HEAT HOURS (NHH)
TMinAx	LOWEST DAILY TEMPERATURE (°C)
TMaxAx	HIGHEST MAXIMUM TEMPERATURE (°C)
Ggelo	DAYS WITH TMIN< 0°
Gdisgelo	DAYS WITH TMAX <0°
ETO	EVAPOTRANSPIRATION ETO (mm)

ECOPHYSIOLOGICAL APPROACH

1. CO_2 Assimilation, respiration models

2. RUE – Radiation Use Efficiency

$$B = RUE \times Rg \times 0.5 \times [1- e^{(-ke \times LAI)}]$$

3. TUE – Traspiration Use Efficiency

$$B = K_{BT} \times (T_p / VPD)$$

4. RUE - TUE Models

B = min (B-RUE, B-TUE)

NET PRIMARY PRODUCTIVITY

2 → Introduzione della pianta: ecofisiologia

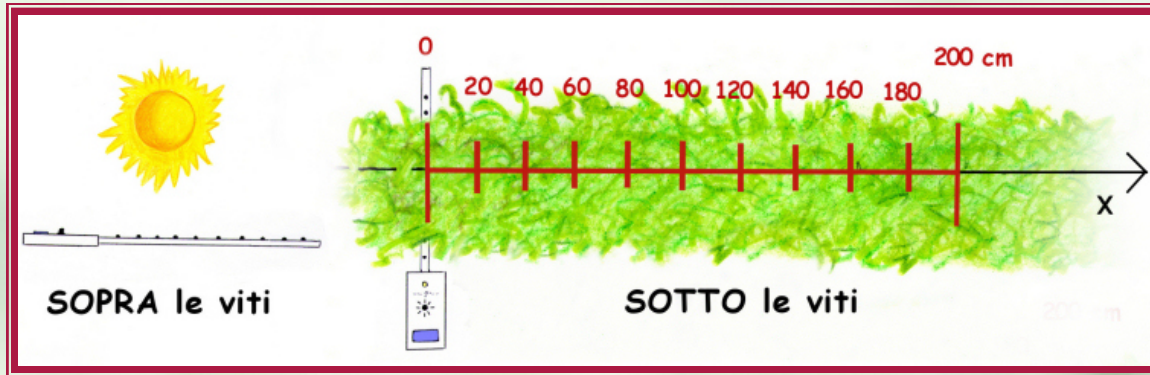
Analizzatore di scambi gassosi LCpro+ → **Assimilazione, conduttanza stomatica, traspirazione**

Barra solarimetrica Multi-Par Probe

↓

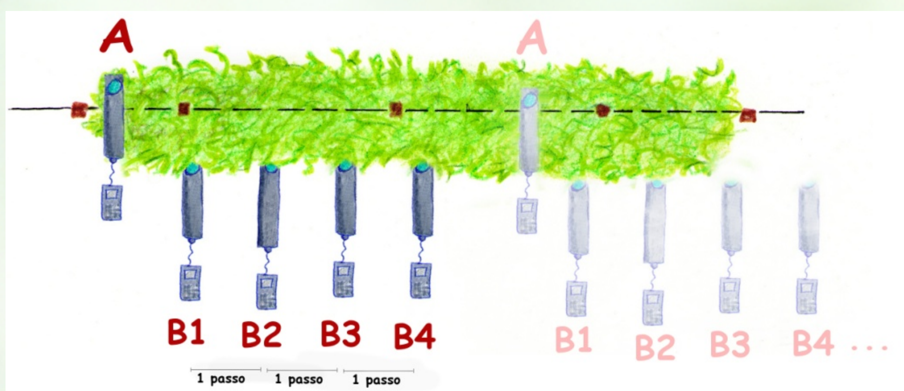
Intercettazione luminosa della chioma (LtInt)

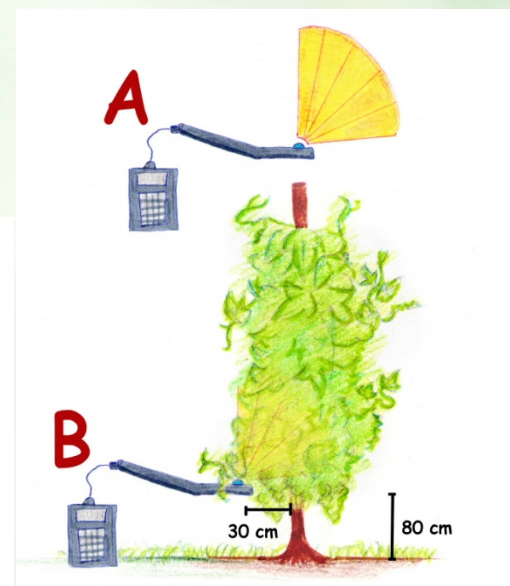
$$LtInt = \sum_{i=1}^{10} (d_i - RIL) \Big/ (10 \times RIL)$$



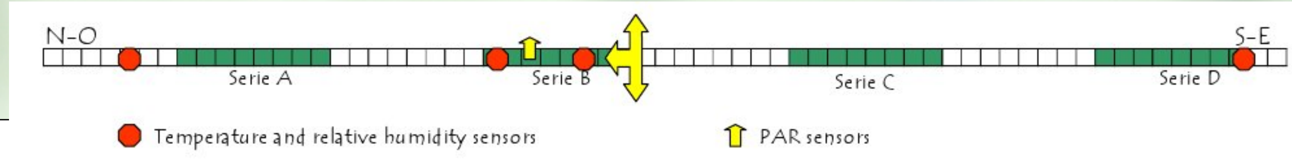
LAI-2000 Plant Canopy Analyzer

Leaf Area Index (LAI)

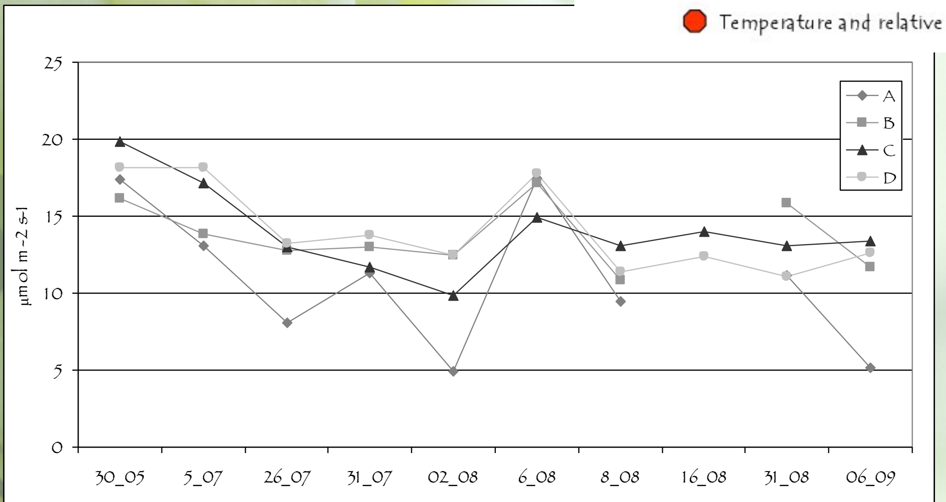




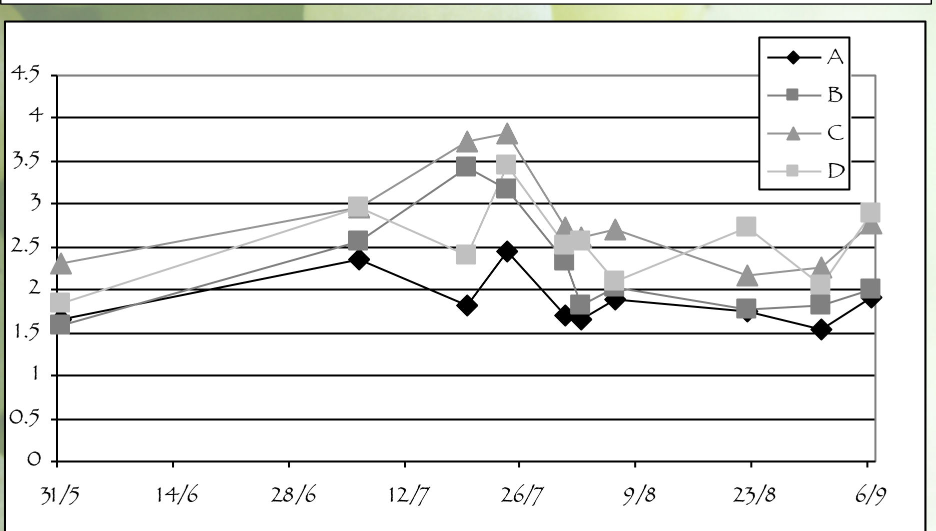
…some results…



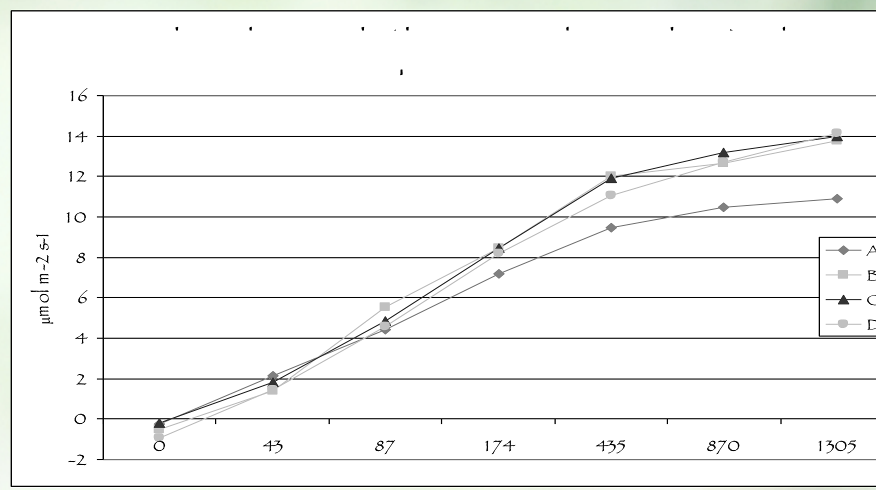
Barbera Vineyard in Grugliasco



Trend comparison of maximum Assimilation Rate (Amax) of four repetitions of Barbera vine in Grugliasco (TO), 2012

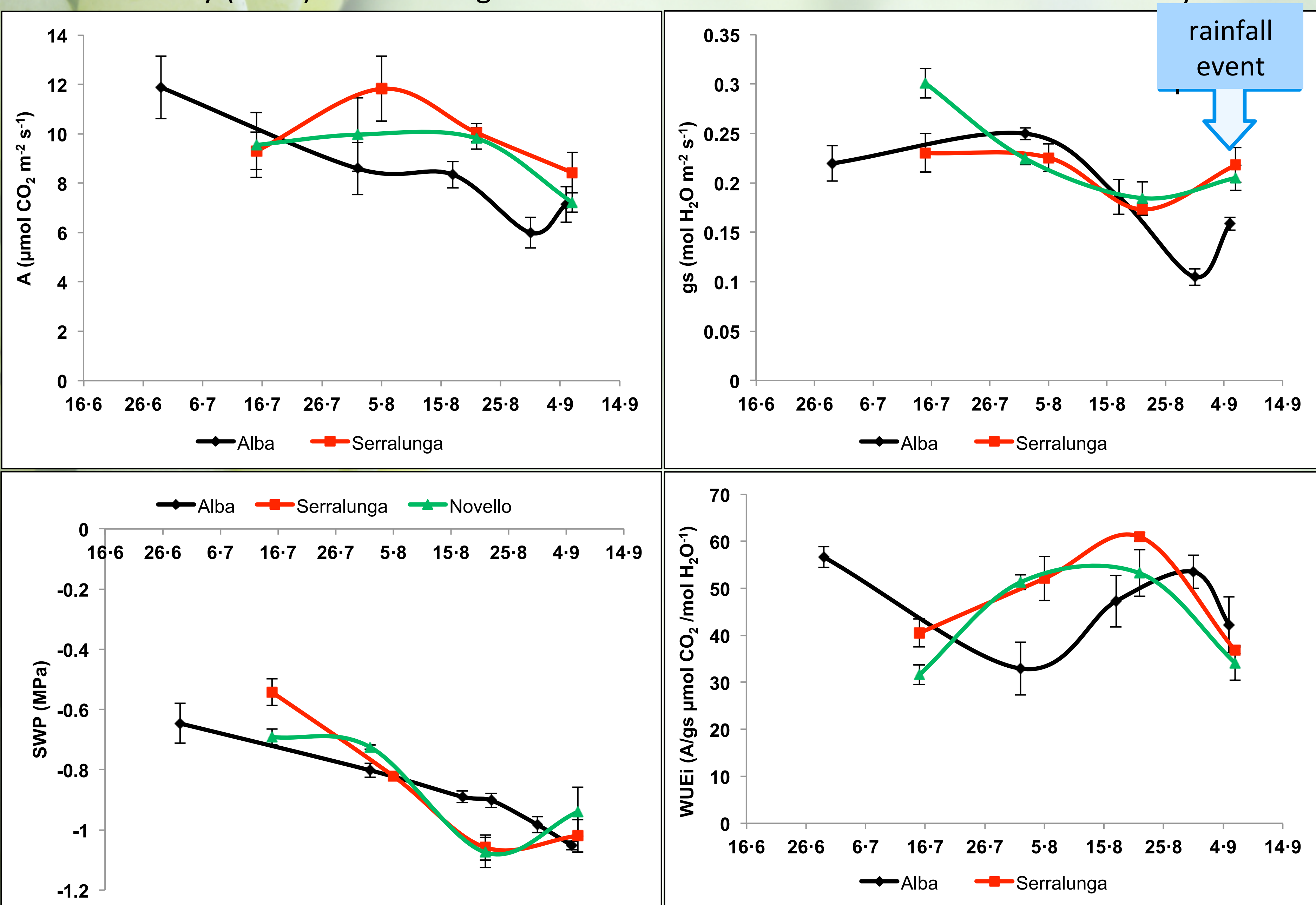


Trend comparison of Leaf Area Index in four repetitions of Barbera vine in Grugliasco (TO), 2012

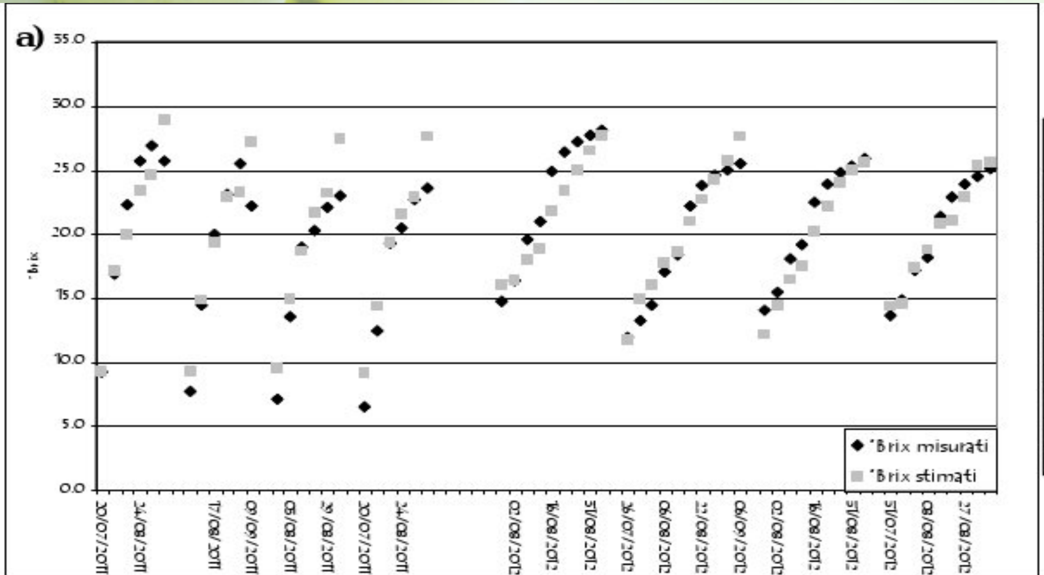


Trend comparison of Assimilation in four repetitions of Barbera vine in Grugliasco (TO) with PAR range from 0 to 1500 µmolm-2s-1, 2012

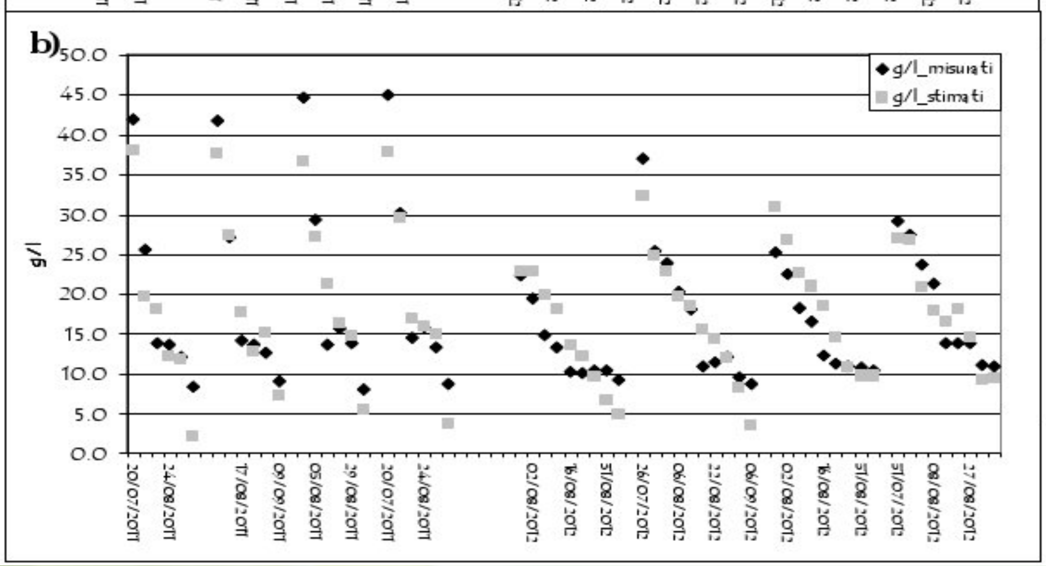
Assimilation (A), stomatal conductance (gs), stem water potential (SWP) and water use efficiency (WUE) trend during the summer seasons 2011 in three different vineyards.



Barbera 2011-2012: comparison between TSS (a) and TA (b) observed and estimated data curves, between veraison and grape harvest, using multiple regression models. Error calculation of the simulation model

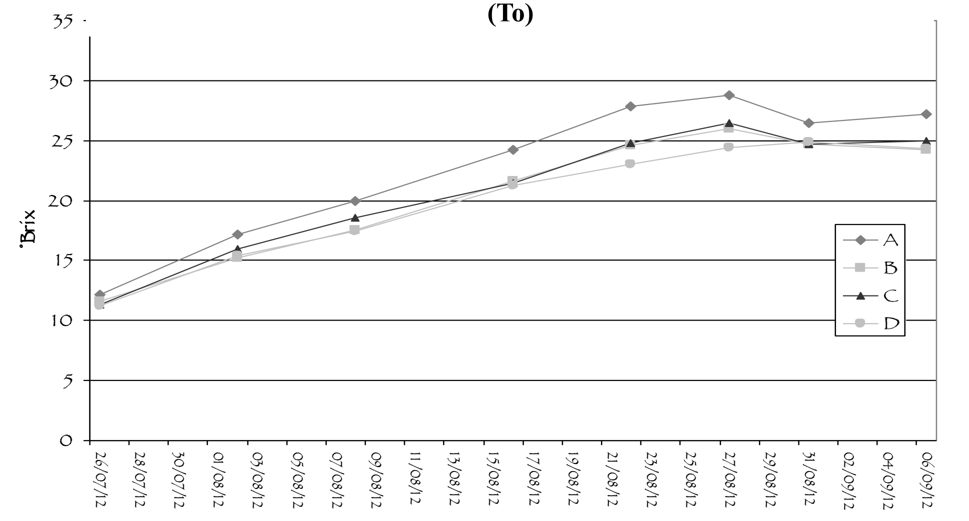


°Brix	MAE	RRMSE	EF	CRM	Slope	Intercept	R2	Signif.
Min	0.00	0.00	-inf.	-inf.	-inf.	-inf.	-inf.	
Max	+inf.	+inf.	1.00	+inf.	+inf.	+inf.	+inf.	
Best	0.00	0.00	1.00	0.00	1.00	0.00	1.00	
A 2011	**1.75**	**10.00**	**0.89**	**0.03**	**0.95**	**1.57**	**0.90**	**0.00**
B 2011	**1.60**	**12.19**	**0.85**	**-0.03**	**0.94**	**0.47**	**0.87**	**0.01**
C 2011	**1.87**	**12.89**	**0.83**	**-0.10**	**0.92**	**-0.23**	**0.94**	**0.00**
D 2011	**1.65**	**12.23**	**0.88**	**-0.09**	**0.99**	**-1.40**	**0.95**	**0.00**
A 2012	**1.68**	**8.57**	**0.83**	**0.06**	**1.12**	**-1.17**	**0.93**	**0.00**
B 2012	**1.01**	**6.09**	**0.94**	**-0.02**	**1.00**	**-0.35**	**0.95**	**0.00**
C 2012	**1.24**	**6.64**	**0.89**	**0.06**	**0.92**	**2.76**	**0.98**	**0.00**
D 2012	**0.71**	**4.28**	**0.96**	**0.01**	**1.02**	**-0.21**	**0.96**	**0.00**

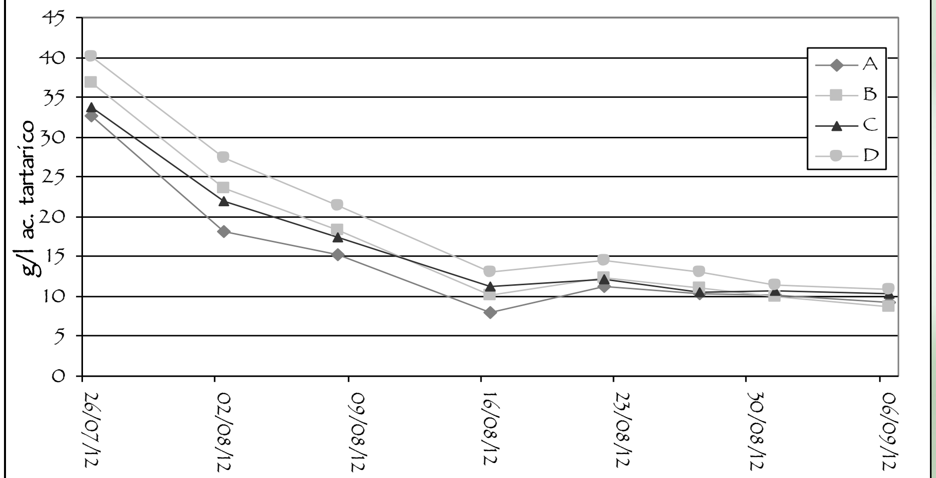


Acidità	MAE	RRMSE	EF	CRM	Slope	Intercept	R2	Signif.
Min	0.00	0.00	-inf.	-inf.	-inf.	-inf.	-inf.	
Max	+inf.	+inf.	1.00	+inf.	+inf.	+inf.	+inf.	
Best	0.00	0.00	1.00	0.00	1.00	0.00	1.00	
A 2011	**3.65**	**22.06**	**0.86**	**0.12**	**0.99**	**2.46**	**0.90**	**0.00**
B 2011	**2.20**	**13.01**	**0.95**	**0.00**	**1.09**	**-1.71**	**0.96**	**0.00**
C 2011	**3.64**	**22.90**	**0.85**	**0.03**	**1.18**	**-3.13**	**0.88**	**0.01**
D 2011	**2.80**	**17.64**	**0.91**	**0.07**	**1.11**	**-0.62**	**0.93**	**0.00**
A 2012	**3.12**	**26.21**	**0.37**	**-0.08**	**0.60**	**4.59**	**0.76**	**0.00**
B 2012	**2.12**	**16.11**	**0.89**	**0.03**	**1.02**	**0.22**	**0.89**	**0.00**
C 2012	**3.33**	**25.65**	**0.45**	**-0.19**	**0.70**	**2.54**	**0.93**	**0.00**
D 2012	**2.28**	**13.97**	**0.86**	**0.03**	**1.04**	**-0.12**	**0.86**	**0.00**

Total Soluble Solids (°Brix) trend in Barbera grape, 2012. Grugliasco (To)

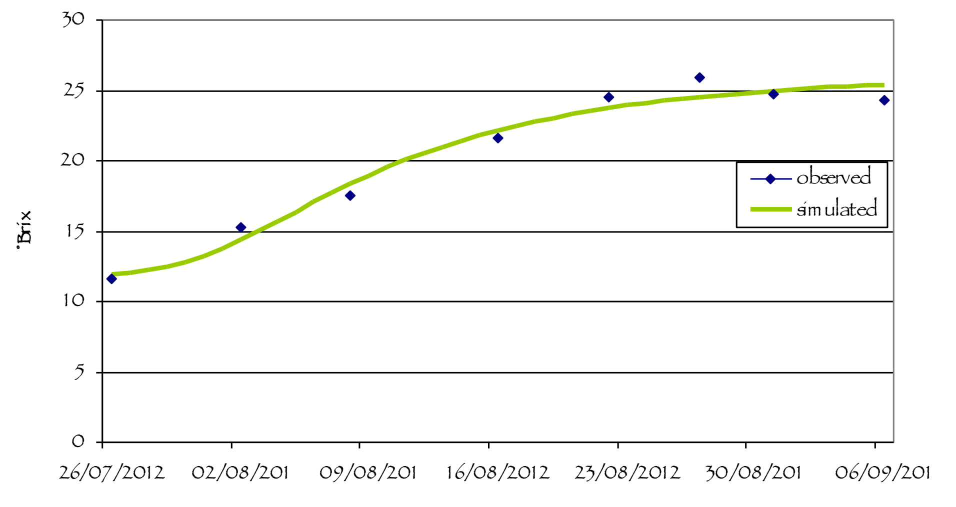


Titratable acidity (g/l ac.tartaric) trend in Barbera grape, 2012. Grugliasco (To)

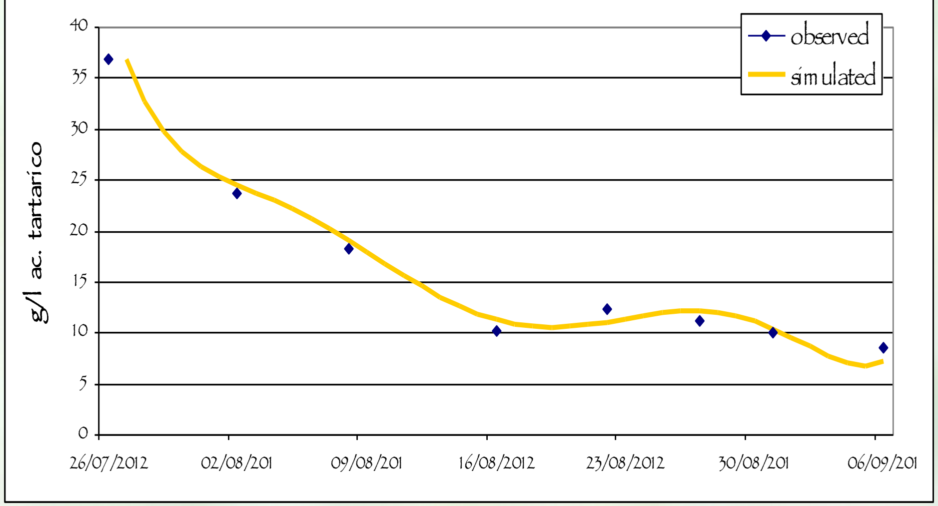


Trend of quality parameters simulated

Comparison between TSS observed and estimated data curves in Barbera grape, 2012. Grugliasco (To)



Comparison between TA observed and estimated data curves in Barbera grape, 2012. Grugliasco (To)



BIOPHYSICAL APPROACH

The "complication" of hilly vineyards

Normally turbulent sensible (and latent) heat flux from sonic anemometer data are evaluated with the implied hypothesis of homogeneous, uniform and horizontal plane

The condition $\overline{w} = 0$ is imposed and the turbulent heat fluxes are evaluated in the horizontal plane

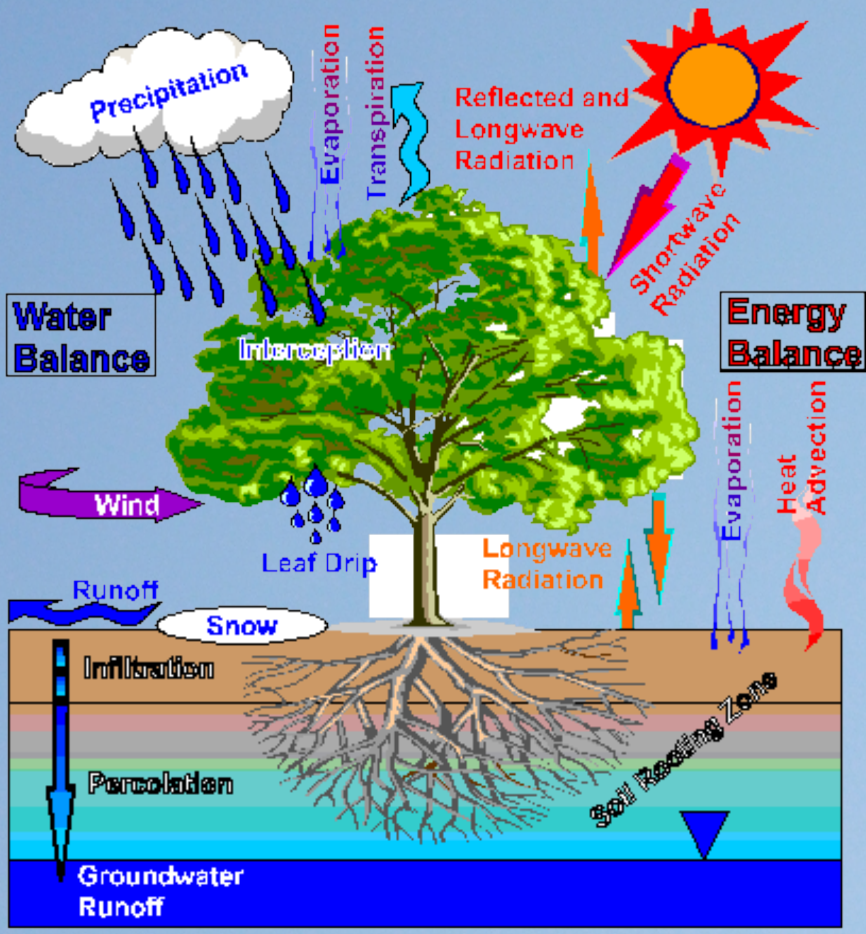
Hilly vineyards are not horizontal (and not uniform and not homogeneous) → need to evaluate the fluxes with respect to the streamline plane

Execution of a planar fit (mean values over a "long" period in order to avoid short term variations: 30 min)

Fluxes are evaluated every 30 minutes

- z axis is fixed (perpendicular to the plane)
- x-y vary in the time: *u* wind speed is aligned along the mean wind speed (// to the plane)

The UTOPIA model



University of TOrino model of land Process Interaction with Atmosphere

New version (2010) of LSPM

(*Land Surface Process Model*)

(Cassardo et al., 1992)

1-D diagnostic model

Vegetation – 1 layer (“BIG LEAF”)

Vegetation classes characterized by:

- Minimum stomatal resistance
- Leaf diameter
- Root depth
- Albedo
- Emissivity
- **Height**
- **Cover**
- **Leaf Area Index (LAI)**

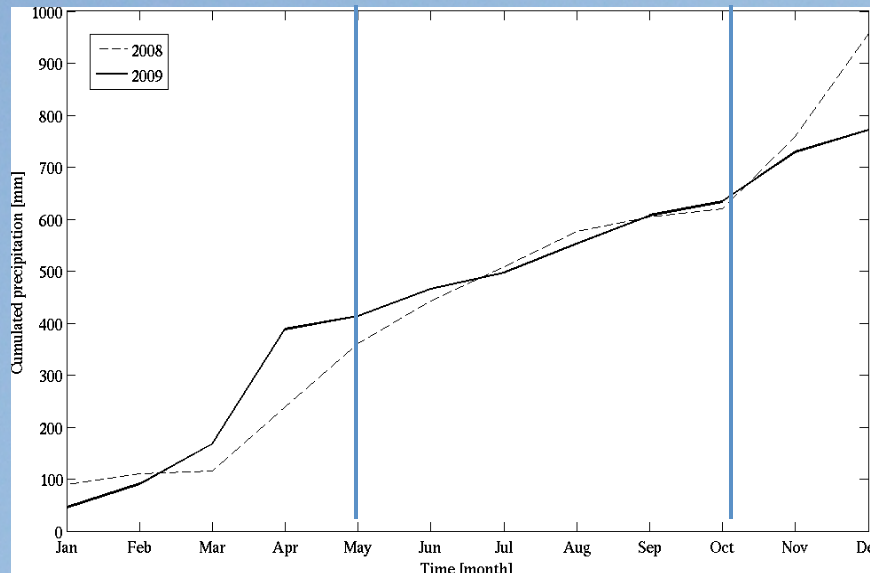
Radiative balance

$$R_n = H + \lambda_v E + Q_g + P_h$$

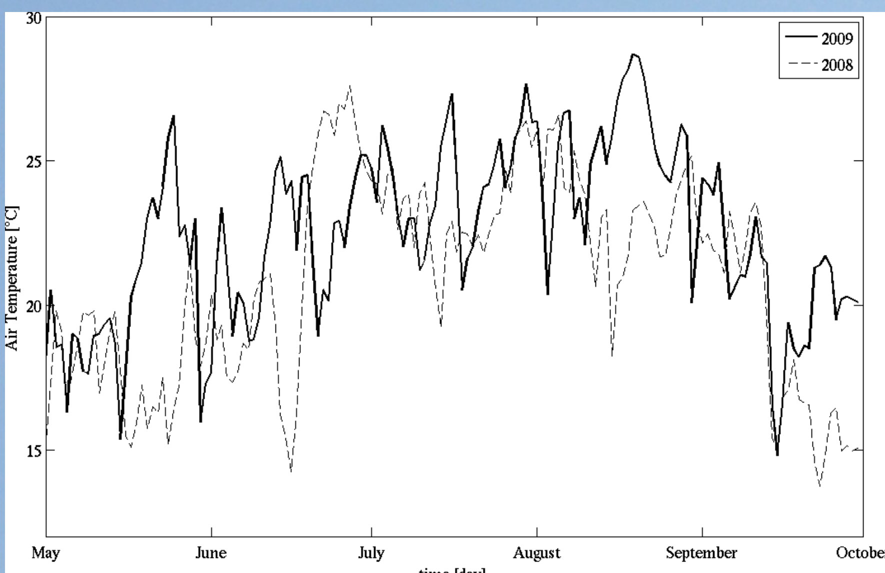
R_n net radiation - available energy flux for:

- evaporation or condensation (air, soil and vegetation)
  $\lambda_v E$ LATENT HEAT FLUX
- air or surface warming or cooling
  H SENSIBLE HEAT FLUX
- soil warming or cooling
  Q_g SOIL HEAT FLUX
- photosynthesis P_h

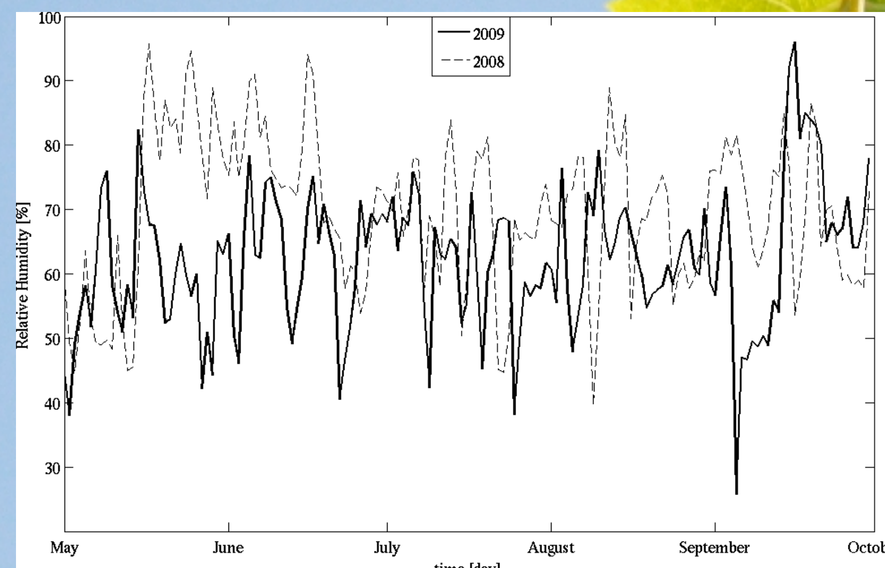
Meteorological data 2008-2009



Cumulated precipitation (mm)

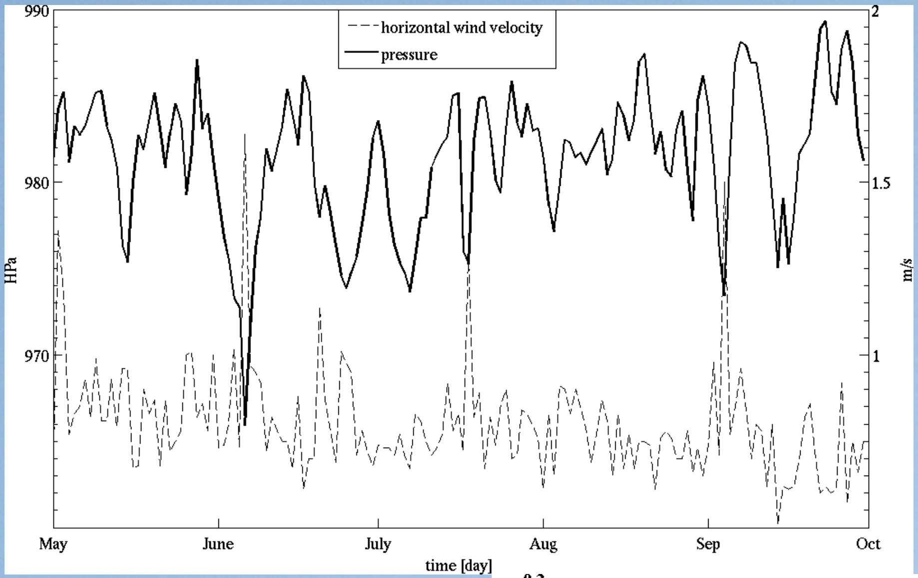


Air temperature (°C)



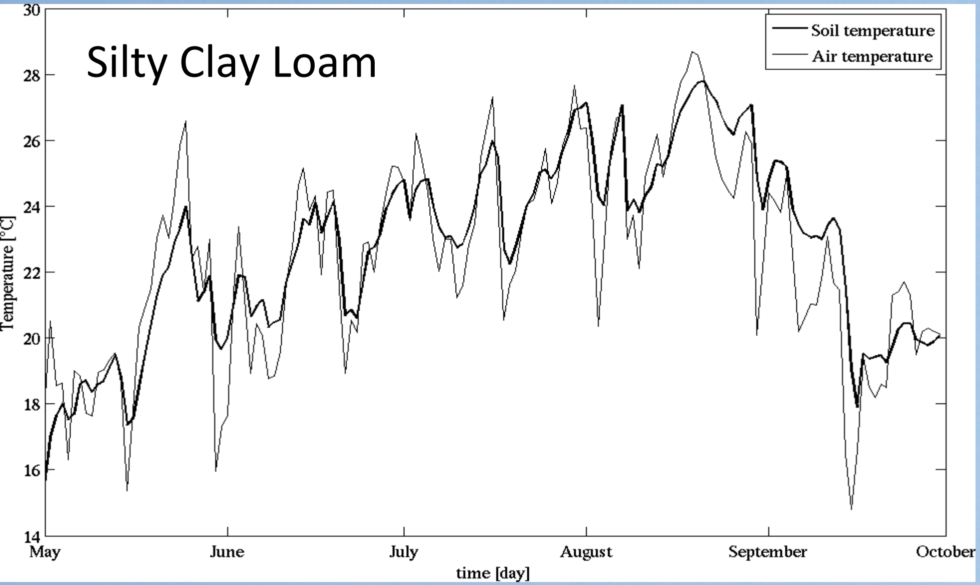
Relative humidity (%)

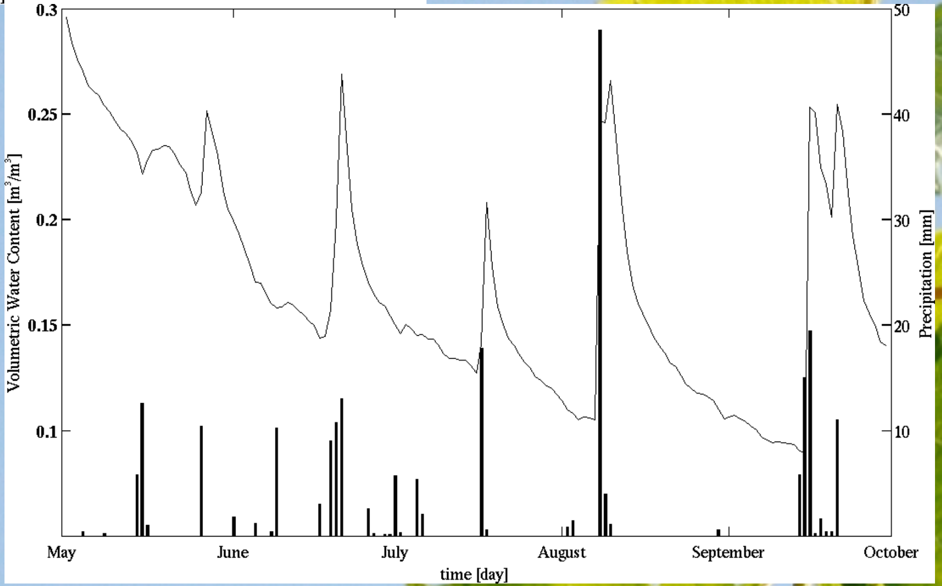
Other data in 2009



Pressure (hPa)

Wind speed (m/s)

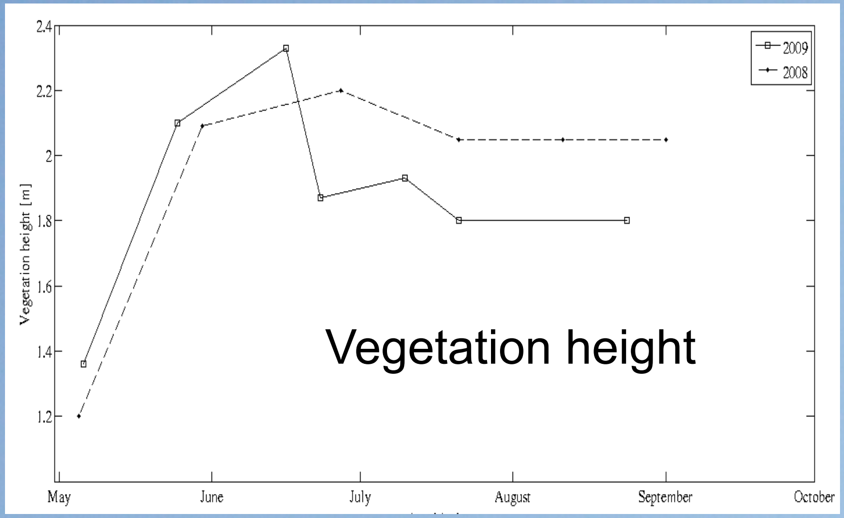


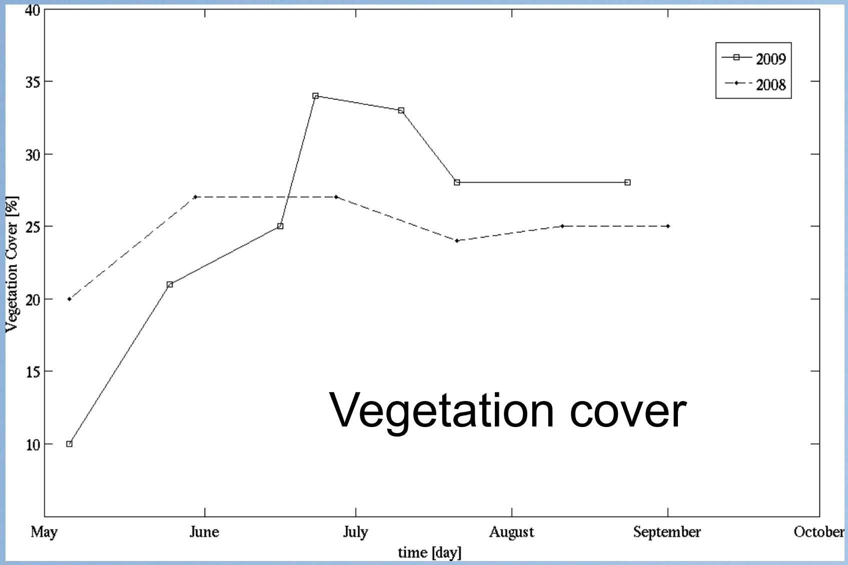


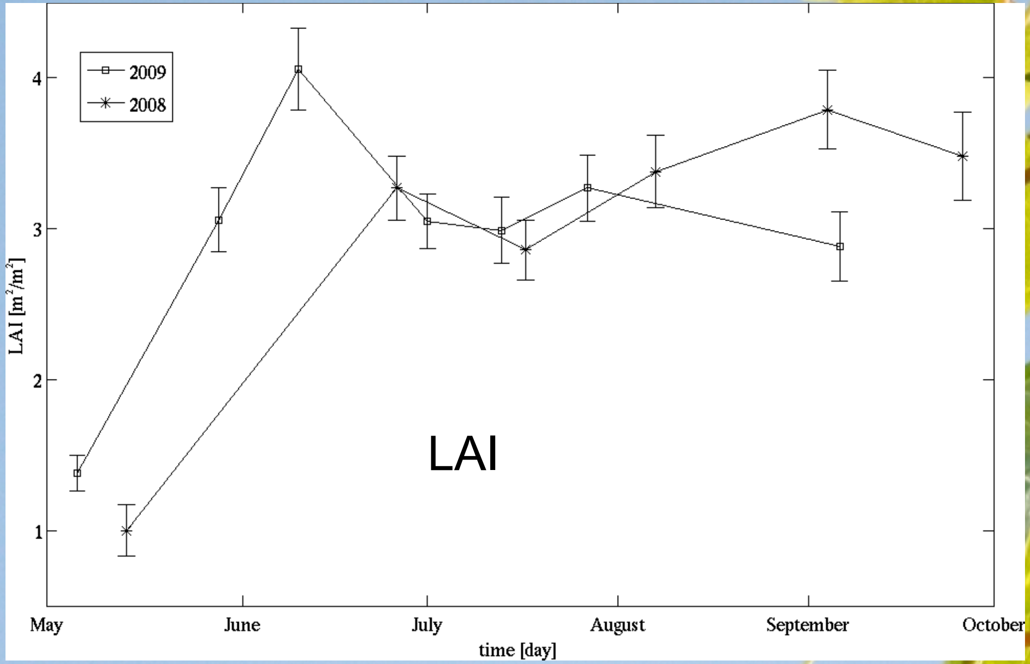
Soil temperature (°C) 5 cm

Daily precipitation (mm) and soil moisture

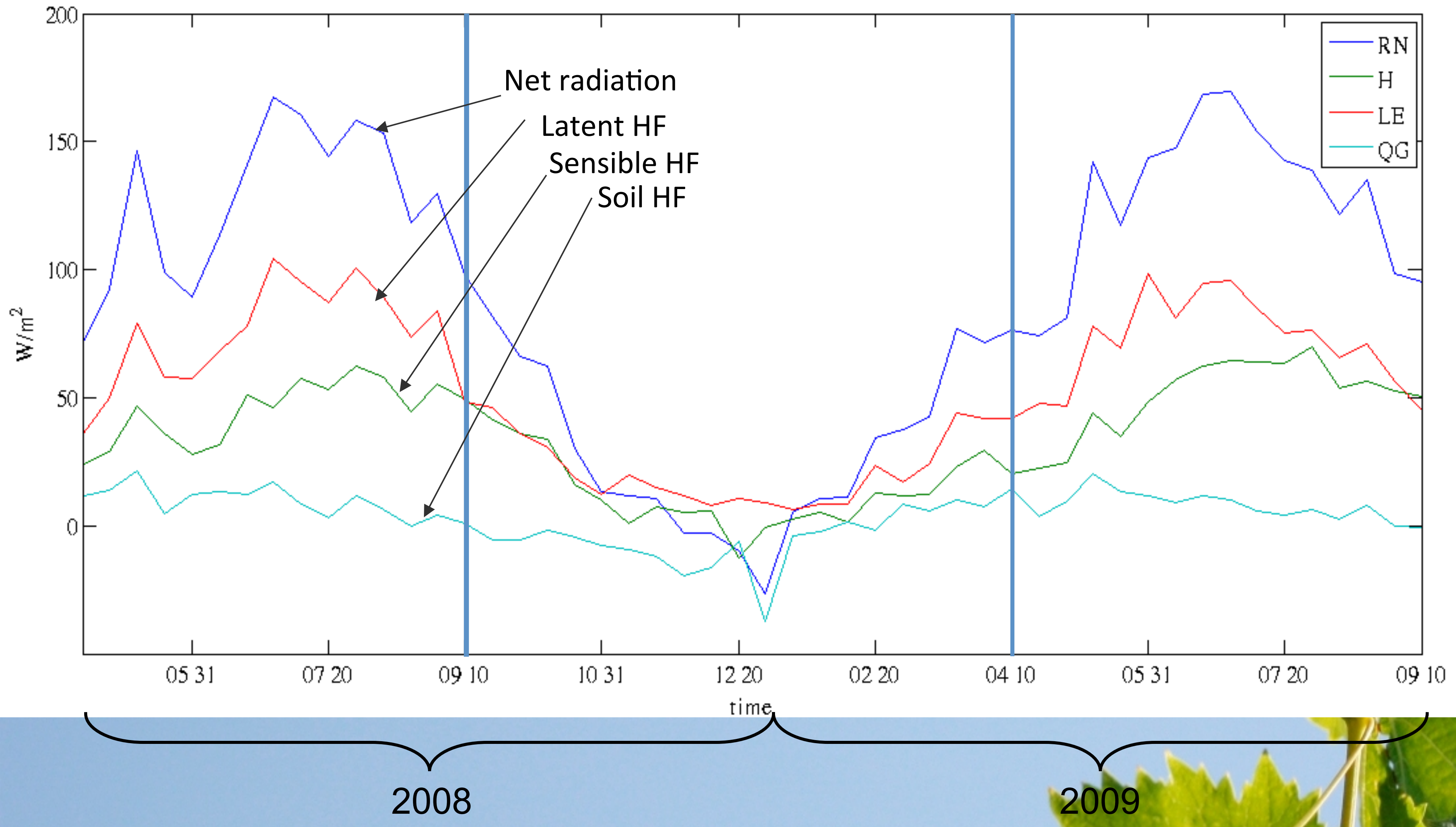
Vegetation parameters 2008 - 2009







UTOPIA simulations: energy balance 2008 - 2009



Heat flux physics in UTOPIA

Turbulent fluxes, flux-gradient law by analogy with Ohm's Law

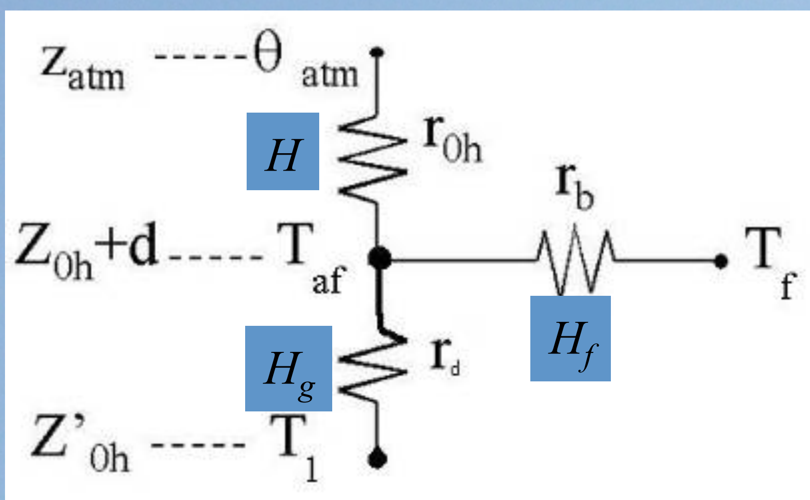
$$H = \rho c_p \overline{w'\theta'}$$

$$H = -k \frac{dT}{dz}$$

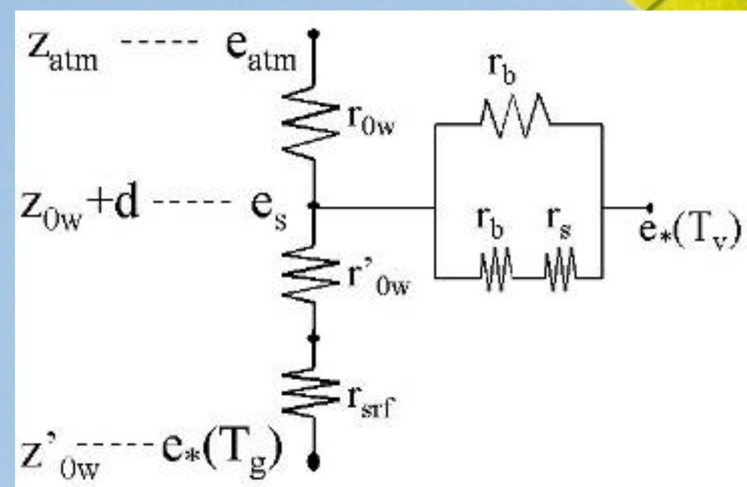
$$H = H_f + H_g$$

$$H_f = \rho_a c_p s_b \left(T_f - T_{af}\right) \sigma_f$$

$$H_g = \rho_a c_p s_d \left(T_1 - T_{af}\right) \left(1 - \sigma_f\right)$$



Sensible heat flux for a vegetated surface



Latent heat flux for a vegetated surface

Why UTOPIA?

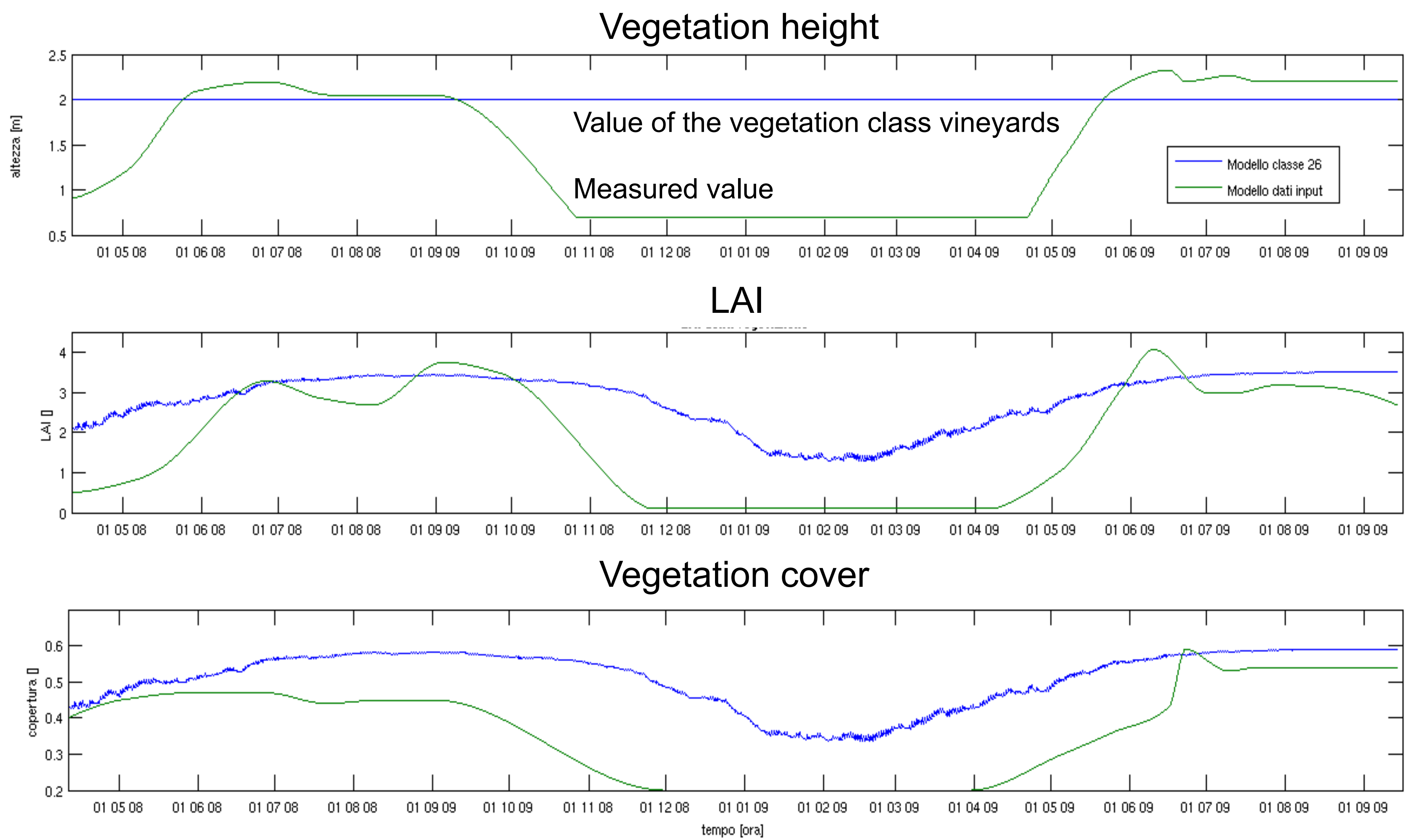
Continuation of a study previously carried out on stomatal conductance of *Nebbiolo** wine

Preliminary results:

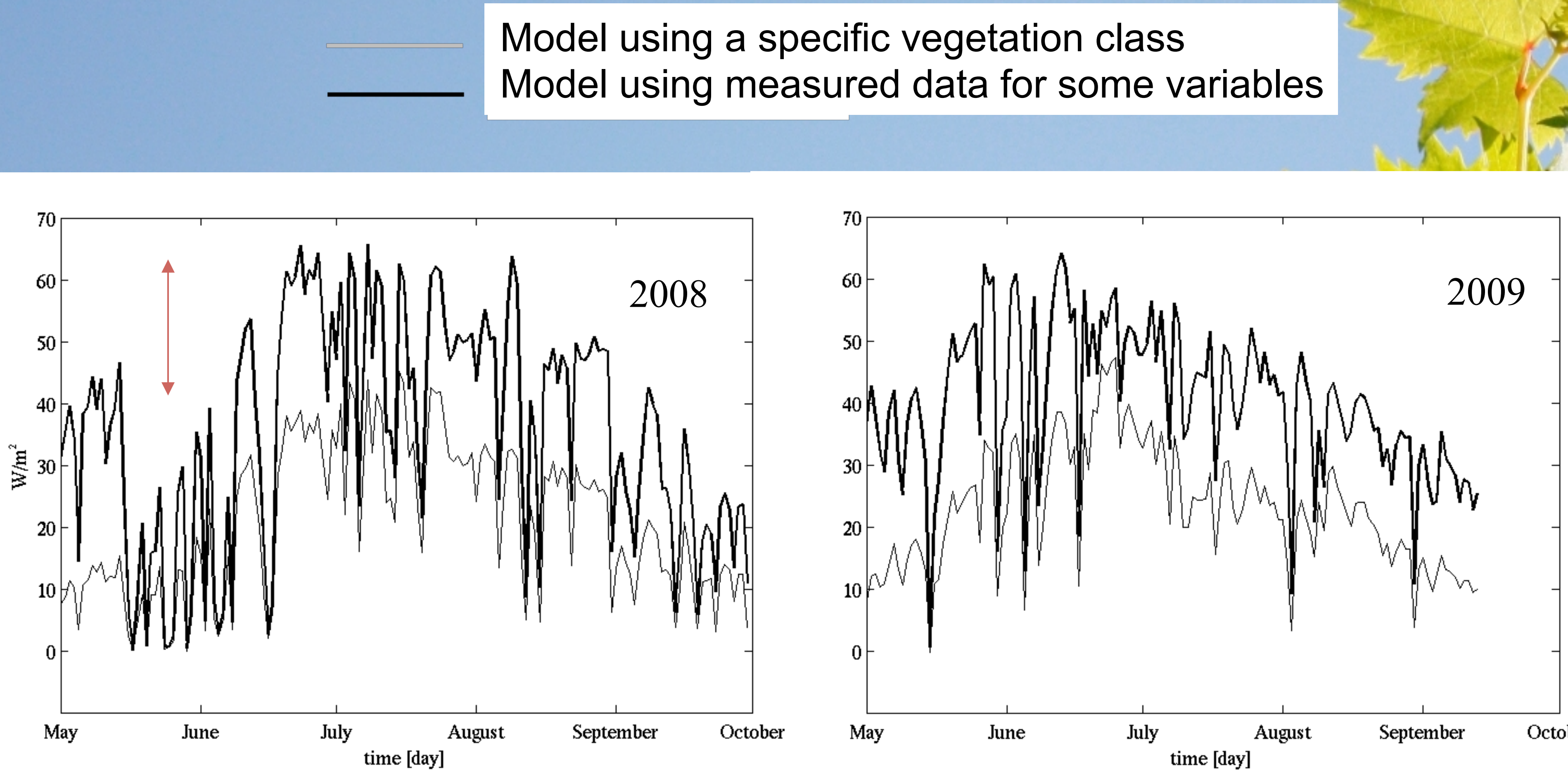
- First experimental section over vine (gas exchange analyzer)
- Study of the link between physiological and meteorological factors through the stomatal conductance
- UTOPIA: New parameterization of transpiration in function of temperature and air humidity, radiation and CO_2
- Decrease of the conductance at CO_2 concentration higher than environmental values (climatic perspective)

* Prino S., Spanna F., Cassardo C. 2009

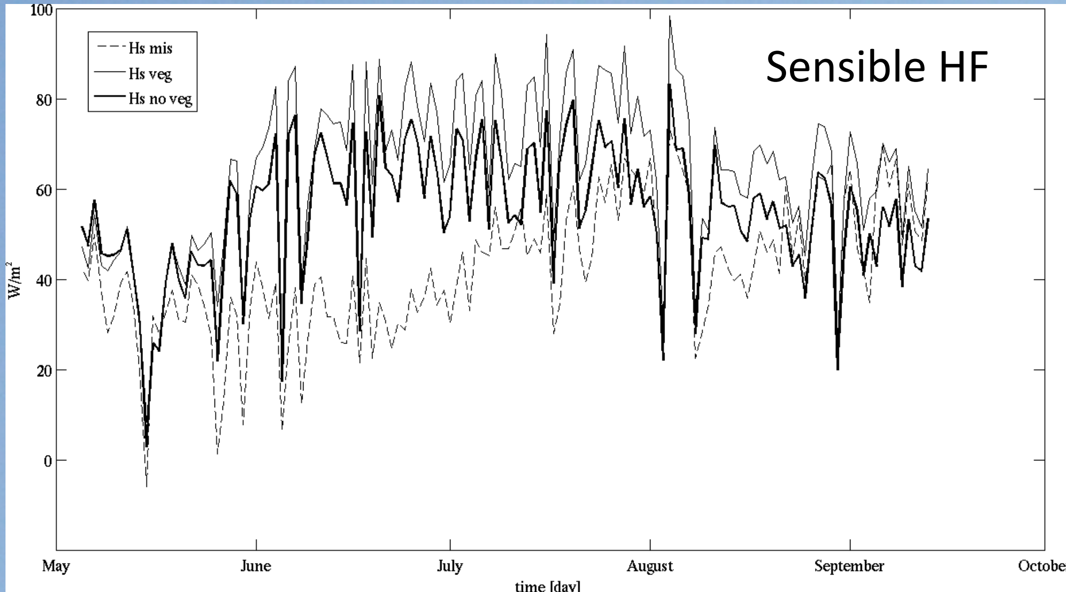
UTOPIA simulations: vegetation parameters 2008 - 2009

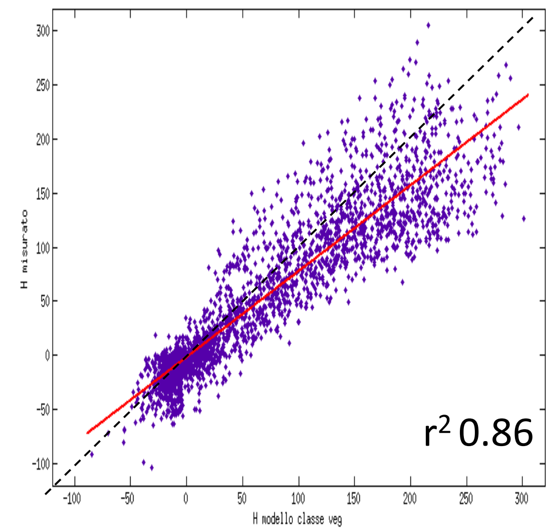


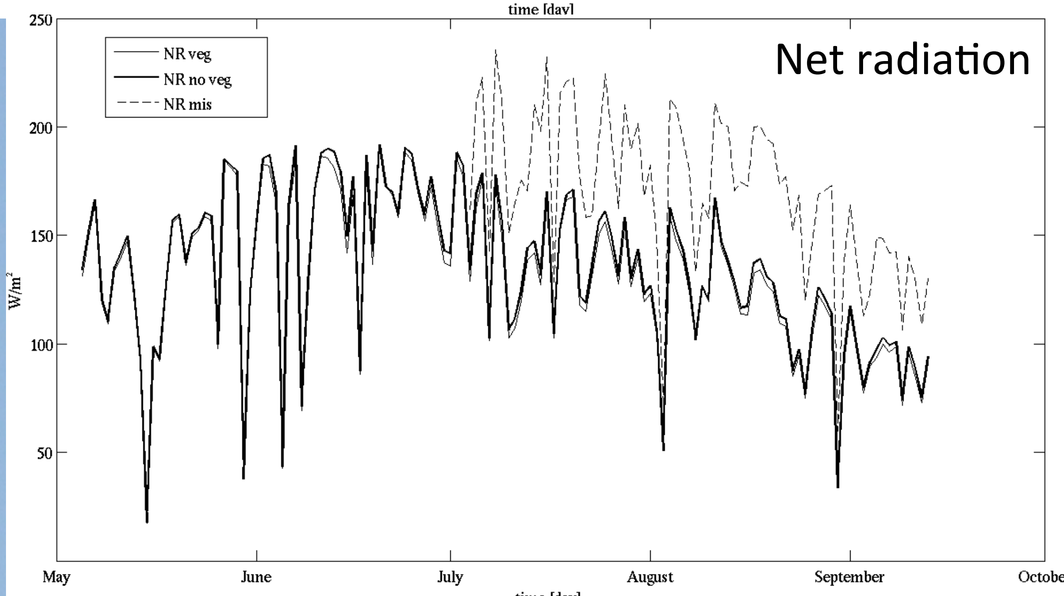
UTOPIA: comparison with different initializations transpiration 2008 - 2009

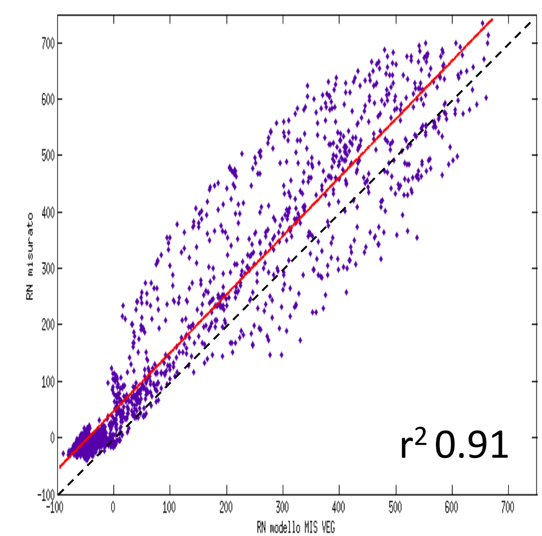


Comparison between UTOPIA and measurements – 2009









NELLA VITE LE CONDIZIONI CLIMATICHE GENERALI E IL REGIME TERMICO, IN PARTICOLARE :

- ✓ **rappresentano fattori che maggiormente influenzano il ritmo di crescita e sviluppo (range termico compreso tra i 10 ed i 20 °C Tm annua)**

- ✓ **influiscono nel determinare le epoche di comparsa delle principali fasi fenologiche e la composizione chimica dell'uva al momento della raccolta**

IMPORTANTE:

Individuare strumenti di facile applicazione che esprimano relazioni tra condizioni meteo e produzione enologica

per fornire agli operatori strumenti di analisi e interpretazione per la gestione e pianificazione della loro attività

Per esprimere numericamente le esigenze climatiche della vite, sono stati elaborati **INDICI BIOCLIMATICI** UTILI A :

- ✓ INDIVIDUARE LE AREE IDONEE ALLA COLTIVAZIONE DELLA VITE
- ✓ DIFFERENZIARE E DELIMITARE LE DIVERSE ZONE VITICOLE IN BASE ALL'OBIETTIVO PRODUTTIVO CHE SI PERSEGUE

Gli indici agroclimatici servono quindi a:

- ✓ definire quantitativamente le risorse del territorio in funzione delle esigenze della coltura
- ✓ valutare le caratteristiche di una particolare annata in funzione della coltivazione e non della qualita'

… MA NON CI DANNO INFORMAZIONI SULLE RISPOSTE DELLA PIANTA…

ECOFISIOLOGIA VEGETALE

studia le risposte fisiologiche degli organismi vegetali all'ambiente circostante e alla variabili meteorologiche

Ciò che consente la vita delle piante in uno specifico ambiente è l'adattamento, che può riguardare la specie e il singolo individuo.

QUANTIFICARE LE POTENZIALITA' PRODUTTIVE DELLA PIANTA E STIMARE L'ENTITÀ DEGLI EFFETTI DI STRESS CONTRIBUISCE A PROGRAMMARE GLI INTERVENTI NECESSARI PER OTTIMIZZARE LA PRODUTTIVITÀ VEGETALE

- ✓ **Simulare affidabilmente un agroecosistema consente di considerare fenomeni complessi (es: infestanti, avversità biotiche e abiotiche)**

MODELLO MECCANICISTICO

LIVELLO PRODUTTIVO

POTENZIALE

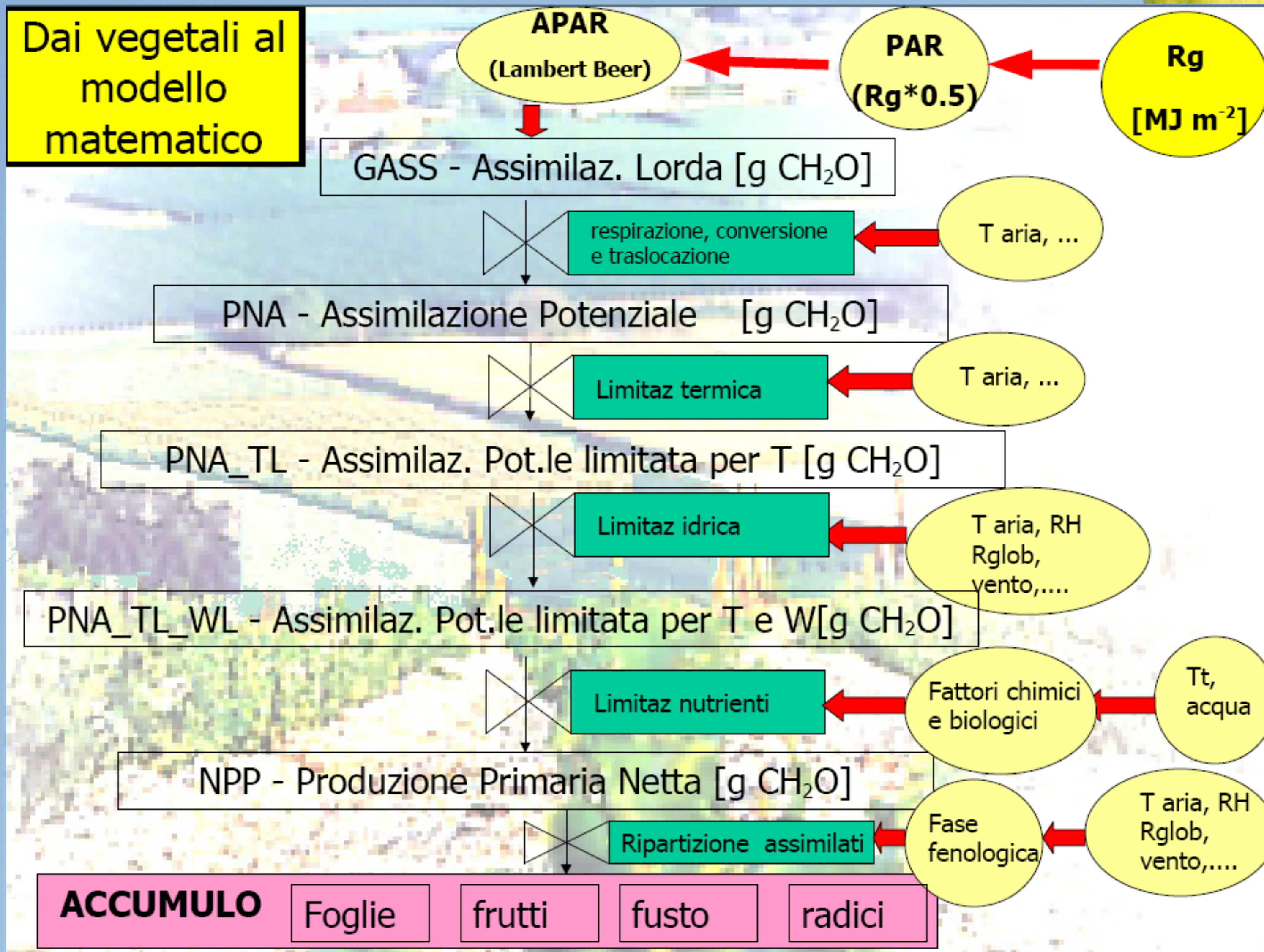
LIMITATO PER TEMPERATURA

LIMITATO PER L'ACQUA

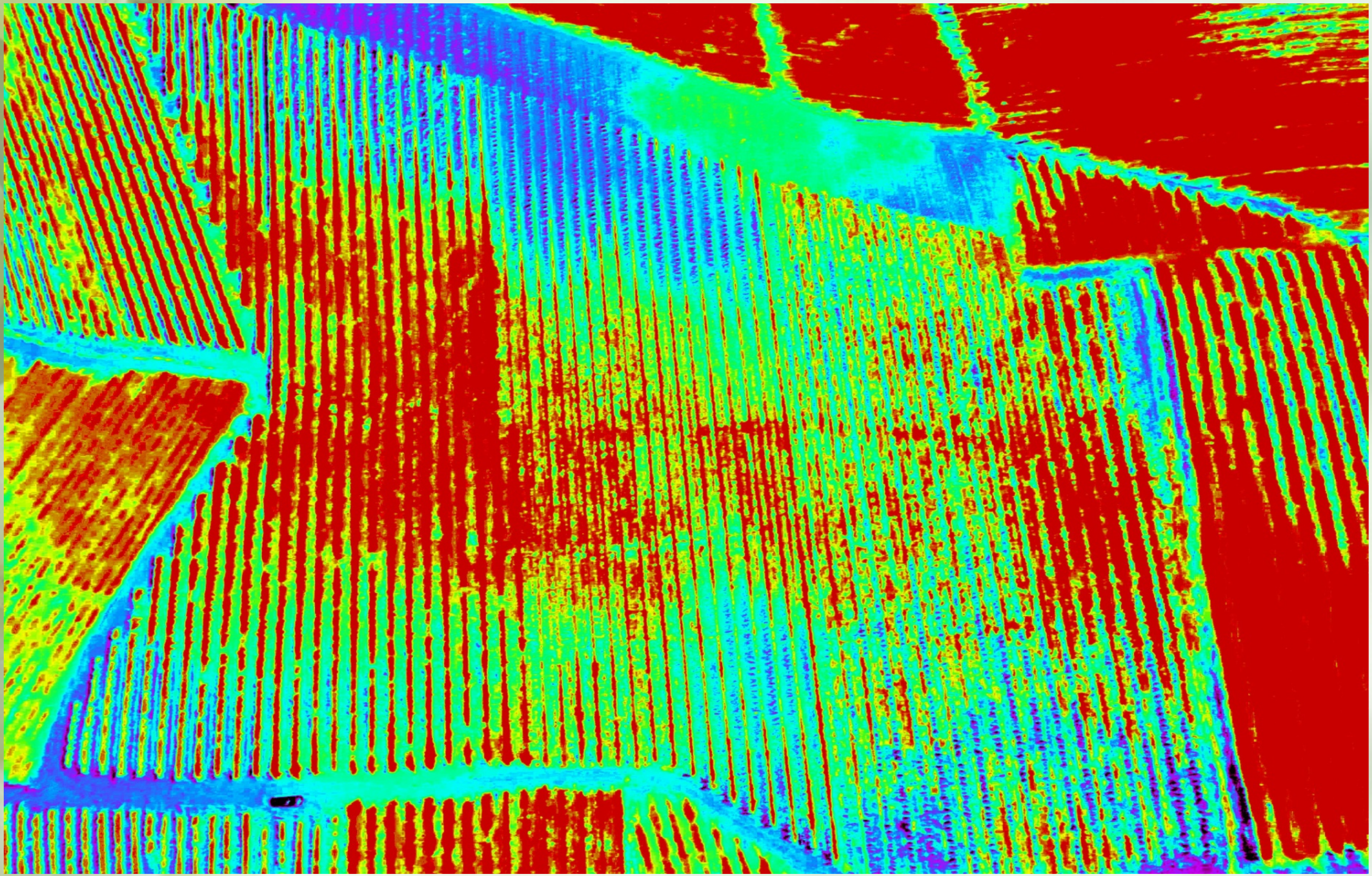
LIMITATO PER I NUTRIENTI

(AVVERSITA' BIOTICHE E ABIOTICHE)

PRODUZIONE FINALE (ripartita tra gli organi)



NDVI- with Drone, 01-08-2013



Conclusions, perspectives, future work

- The work is still *in progress*, and the study involves 2-3 complementary projects
- Interesting results considering an integrated approach with agrometeorological, ecophysiological, physical and vinegrowing aspects
- With MACSUR we have the opportunity to involve in the working group other european countries, other modelers, and other dataset of other vinegrowing areas.
- In particular we are going to share data and methods with other groups working in Spain, France and Germany.
- We have the possibility to validate and calibrate models for tree or shrubs species also considering the product quality
- If we understand the "vineyard system" we can also make simulations for future scenarios under climate change conditions

Conclusions, perspectives, future work

- The work is still *in progress*, thus results are quite preliminary and refer to only Cocconato station and Barbera vineyard
- 2008 and 2009 seasons are climatically different
  - Good opportunity to examine several climate ranges
- Broad consistence between the meteorological factors and the components of energy and radiation balances, soil variables
  - To better quantify these considerations, it is necessary to examine also the data of the other two stations (work in progress) and the data of the 2010 (in measurement)
- The application of UTOPIA model at local scale can provide a wide range of variables difficult to measure extensively
  - It can be possible to assess the climatology of these parameters in the wine regions
  - These parameters can be linked with wine quality
- Need to check UTOPIA to be confident on these values – critical points are:
  - Influence of tilting on solar radiation (done)
  - Initial and boundary conditions of vegetation parameters (LAI, cover, height, …)
  - Accurate description of soil texture