European Commission
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Poljoprivredni fakultet
Univerzitet u Novom Sadu
(PFNS)

Università degli Studi Firenze
DISPAA
Dipartimento di Scienze delle Produzioni Agroalimentari e dell'Ambiente

Universitaet fuer Bodenkultur Wien
(BOKU)

Serbia for Excel
H2020-TWINN-2015

$A_gM^+_{net}$

International Summer School in agrometeorology and crop modelling

Book of lectures and exercises

Introduction

Challenges in agrometeorological research and application

Agrometeorology: from fundamental to applied

Agrometeorological models, fundamentals

Topic 1 – Agrometeorology

Crop growth factors: radiation, energy balance, and temperature

Crop growth factors: water and water balance

Impact of weather extremes on crop growth and adaptation options

Measuring microclimates: challenges and applications

Physics of the boundary layer

Topic 2 – Numeric Weather Prediction

Parameterization of processes in soil-vegetation-atmosphere transfer schemes: water and energy balance

Building SVAT models: epistemiological features

Building SVAT models: an example with the LAPS scheme

Building SVAT models: links with other models

Topic 3 – AquaCrop

AquaCrop model: fundamentals and database management

AquaCrop manuals

Results - Presentations by students

Agrometeorological measurements

Numeric Weather Prediction

AquaCrop modelling

POLJOPRIVREDNI FAKULTET UNIVERZITET U NOVOM SADU
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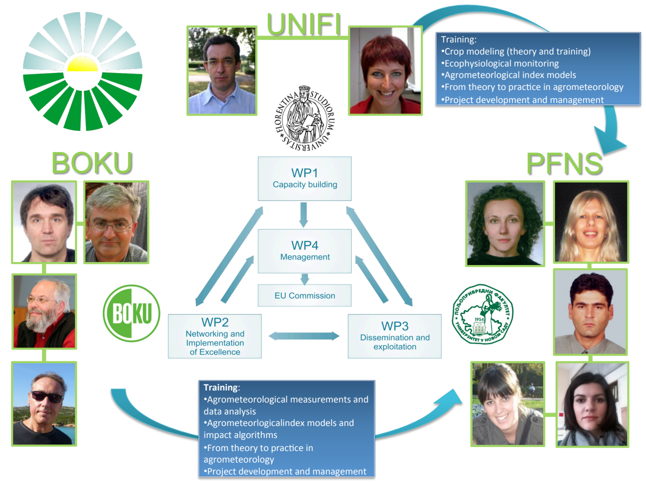
AgMnet INTERNATIONAL SUMMER SCHOOL IN AGROMETEOROLOGY AND CROP MODELLING

27 June – 01 July 2016
Novi Sad, SERBIA

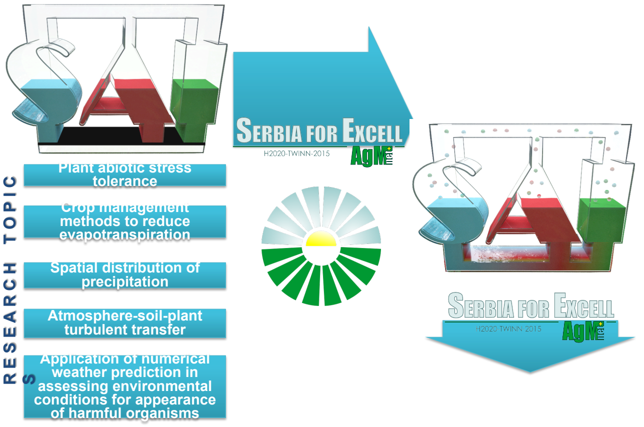
Serbia for Excell
H2020-TWINN-2015

SERBian-Austrian-Italian (SAI) partnership FORcing EXCELLence in ecosystem research

Welcome



Serbia for Excell
OPENNING
Summer School, Novi Sad, June 2016



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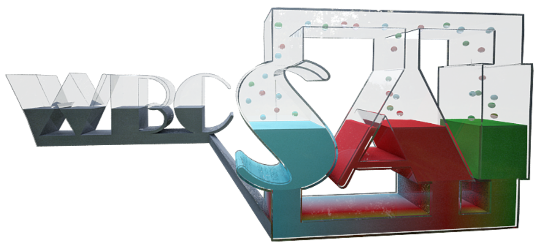
Summer School, Novi Sad, June 2016

PROJECT PLAN

"... is just a wishful thinking if goals are not achievable"



Armenia, Austria, Bosnia and Herzegovina, Bulgaria, Croatia, Czech Republic, Hungary, Italy, Republic of Macedonia and Turkey.

Serbia for Excell
INTRODUCTION
Summer School, Novi Sad, June 2016

I wish you hard work, luck of sleep, endless discussions, new ideas, good energy & beautiful weather ...

EVERYTHING ELSE WILL COME BY ITS OWN!

Summer School 2016

Novi Sad, June 27 - July 1 2016

Serbia for Excell

Josef Eitzinger

Institut für Meteorologie, Universität für Bodenkultur, Wien

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http://www.boku.ac.at/

With special thanks to Federica Rossi (Italy) and Branka Lalic (Serbia) for providing some slides

Agrometeorology plays an increasing important role in agriculture and food production !

Why?
Global change
leads to
higher risks in agricultural production
and less resources for more people.

The top 100 questions of importance to the future of global agriculture

J. Pretty et al., Int. J. Agric. Sust. 8(4), 2010, 219–236

Agriculture unprecedented combination of drivers is **population growth**, dietary shifts, **energy and resource unsecurity**, **climate change** and variability.

The goal is no longer simply to maximize productivity, but to optimize across a far more complex landscape of production, rural development, environmental, social, economic outcomes.

Synergies and dialogue between policies, social, environmental, economic are fundamental to prioritize investments and research efforts.

The top 100 questions of importance to the future of global agriculture

2600 Km3 globally withdrawn to irrigation: in some Countries 80% of water resources are diverted to agriculture (share variable), with increasing competition for urban and industrial usage. In some Country the importance is such that in absence great economic hardship would occur with potential for land abandonment.

Increasing demand (rising population, rising incomes, diet shifts to more water-intensive products) and uncertainties (climate).

Interventions required across scales: field – communities - watershed, catchcements - river basins with focus to increase "green" and "blue" water productivity.
How to optimize the allocation (agriculture, environmental functions)?
What approaches to develop to increase water-use efficiency, and their cost-effectiveness?

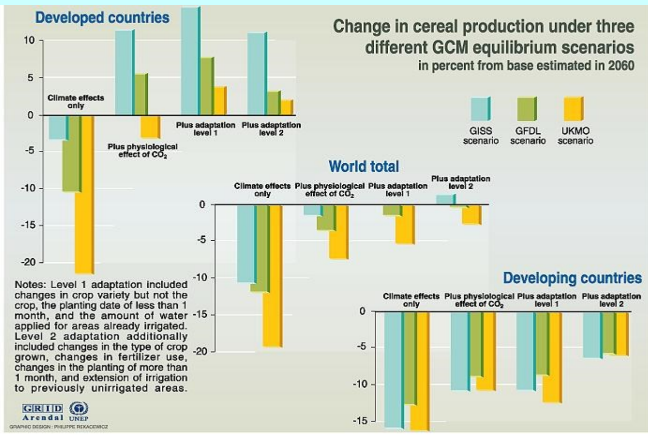
The top 100 questions of importance to the future of global agriculture

Markets and consumption: food supply chain, food standards, LCA, energy, C footprint, environmental impact.

As energy prices rise, how can agriculture increase its efficiency and use fewer inputs to become economically sustainable and environmentally sensitive, yet still feed a growing population?

Agricultural development: networking, solidarity, reciprocity and exchange, farmer participation in technological development.

Farmers involvement enables novel technologies and practices to be learned directly, adopted and adapted. Agricultural, Weather, Climate, Water Sevices services are vital elements to address needs and provide support and critical advises.



Source: Climate change 1995, Impacts, adaptations and mitigation of climate change: scientific-technical analyses, contribution of working group 2 to the second assessment report of the intergovernmental panel on climate change, UNEP and WMO, Cambridge press university, 1996.

Why family (traditional) farms are so important for global food security and welfare of countries ?

Family farms produce about 80 percent of the world's food.

84% are smaller than two hectares.

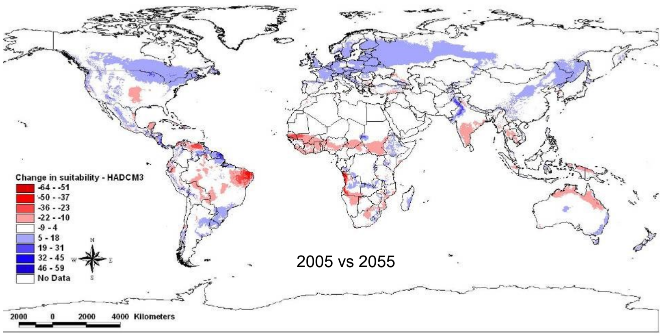
Farms above 50 hectares occupy two-thirds of global farm land.

In low-income countries, farms smaller than five hectares occupy up to 70% of farm land.

In most developing countries farms are becoming smaller and smaller.

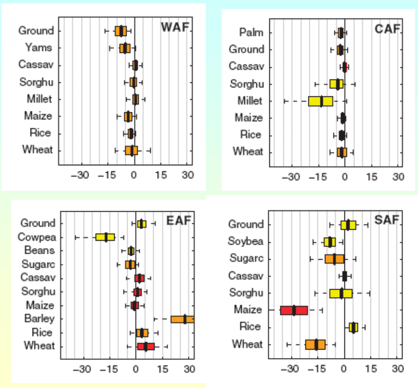
FAO, 2014

Global crop suitability



Lane and Jarvis, 2007

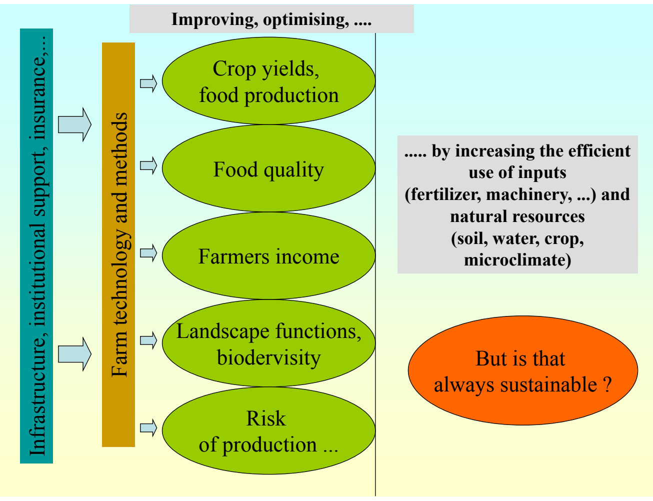
Climate change impacts on crop yields in Africa 2030 vs. 2000 (20 GCMs ensemble mean)

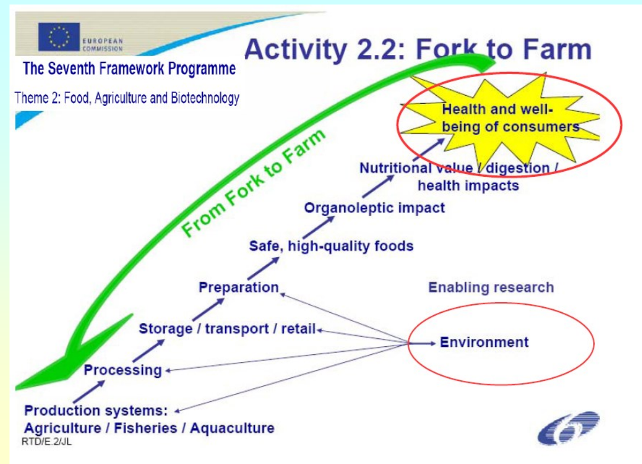


(Lobell et al., 2008. Science)

Challenges for operational agrometeorological application and future research

- **Monitoring activities:**
  Real time and forecasts (drought, extreme weather etc.)
- **Decision Support Systems:**
  Application and user oriented, economic, short and long term focus
- **Climate Mapping:**
  High spatial resolution, considering climate change and crop specific aspects
- **Improving and combining the tools:**
  Remote Sensing, GIS, agrometeorological , crop and irrigation models, measurement systems, data transfer and processing etc.



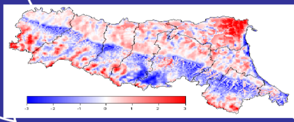


WHY DSS??

Awareness of the risk

Passive protection

Selection of low-risk sites !!!!



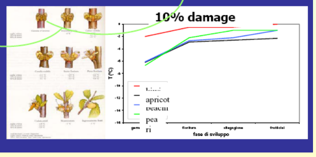
Crop selection

WHY FARMERS NEED PREVISIONS ?

Awareness of the risk

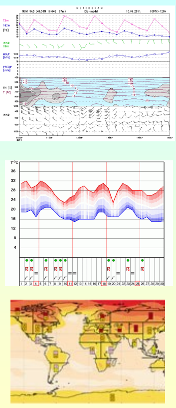
Active protection

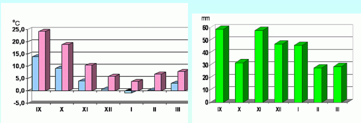
What a probability for a frost tonight? Can the thermal levels predicted compromize my crops at this stage ? Shall I activate my protection devices? What the ratio cost sustained/cost of the possible damage?



Forecasting weather ...

Source: Republic Hydrometeorological Service of Serbia





NWP products of interest in agrometeorology

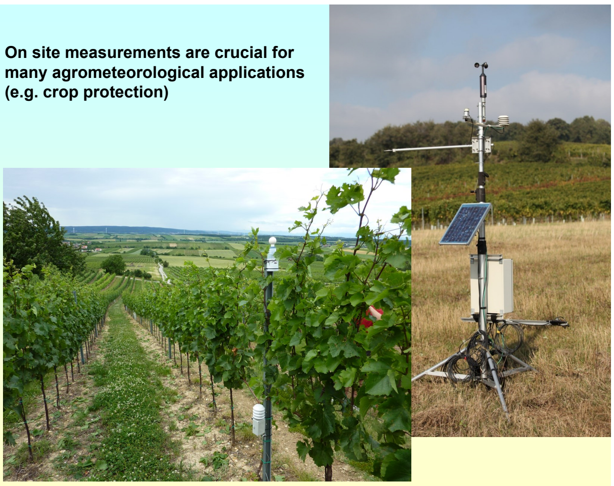
- Short-range weather forecast (out to 5 days)
- Medium-range weather forecast (out to 15 days)
- Monthly forecast (10 to 30 days)
- Seasonal forecast (out to 7 months)
- Climate model simulations (decades)

Lalic, EMS11, September 2011, Berlin, Germany

Frost Advisory

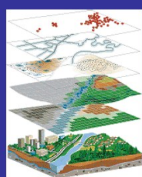
- Forecast of night temperatures depending on foreseen weather conditions and on temperature at sunset. At 10.00 and 01.00 forecasted temperatures and measured temperatures are checked.
- In case of temperatures below 0 °C, a SMS is sent to all registered users

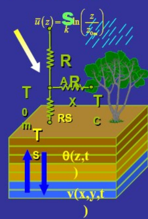
On site measurements are crucial for many agrometeorological applications (e.g. crop protection)



Meteorology-agrometeorology-earth observations

GIS + Earth observation + model



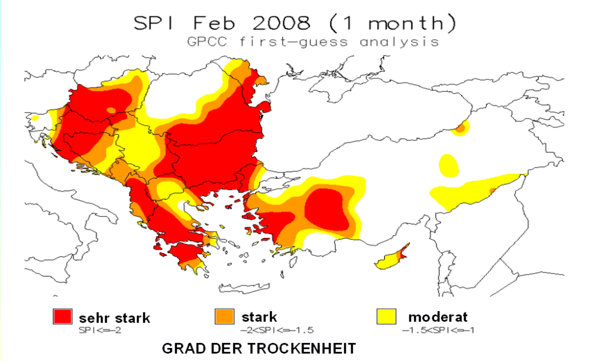


Support GAPs

To improve production (yield, quality)

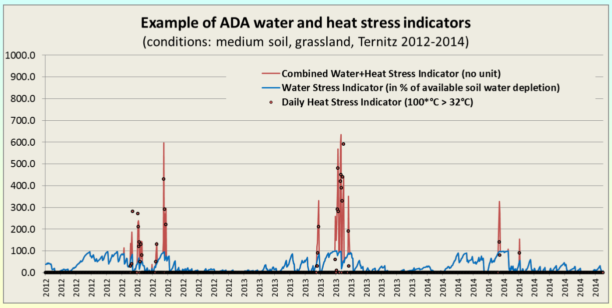
To reduce risks and impacts, to ensure stability and safety

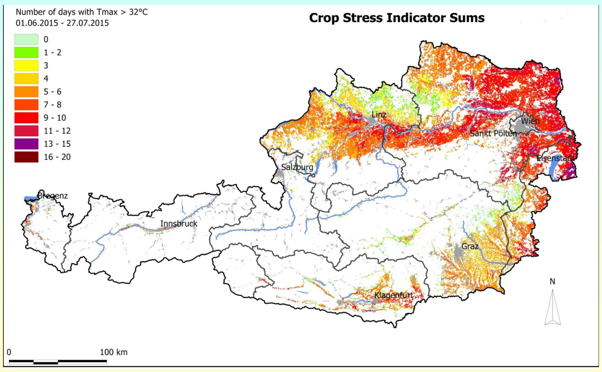
To improve multifunctionality and agro-ecosystem services

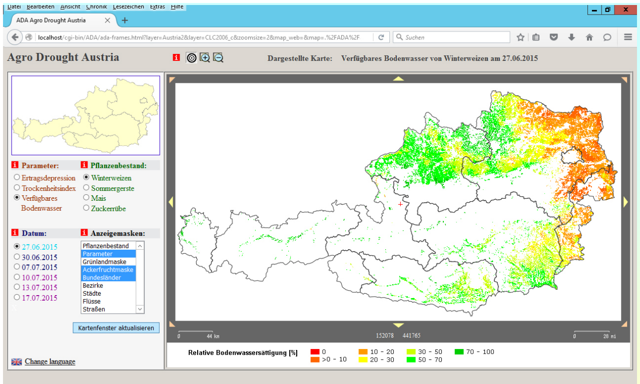


Drought monitoring

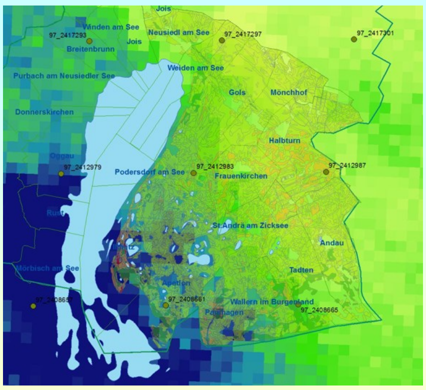
(Source: Susnik, Drought Management Center for South eastern Europe (DMCSEE); www.dmcsee.org)







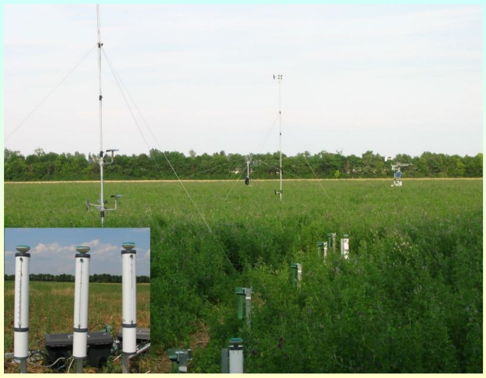
ADA Web-Interface



Combination of spatial data bases: High resolution water balance

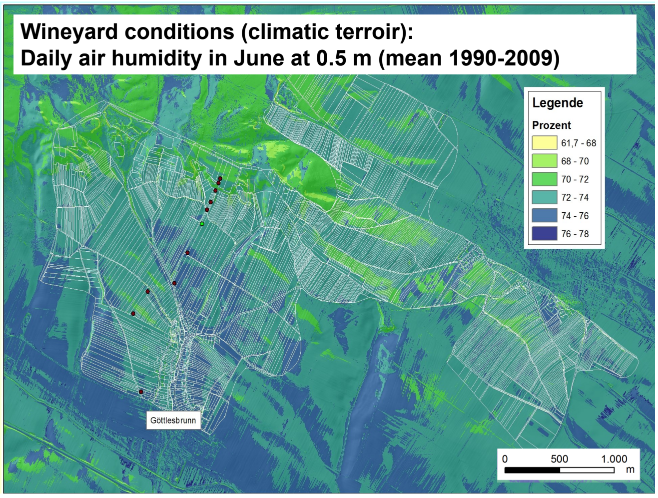
Example: Surface Soil Moisture ASCAT Scatterometer 500m Vs. Soil map

Importance of ground truth data: Transect measurements for high resolution spatial climate mapping



ETgages:

placed in 20m and 80 m distance from the hedgerow (lee side)

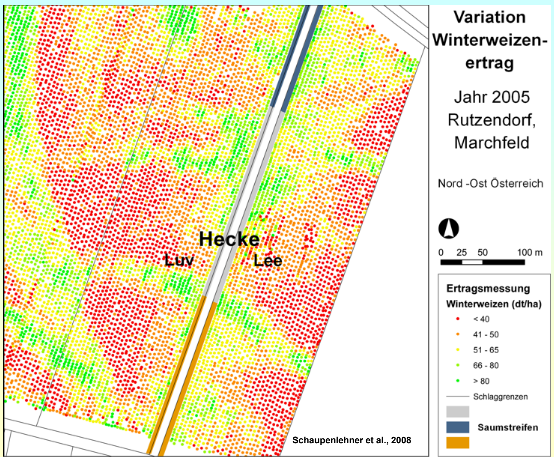


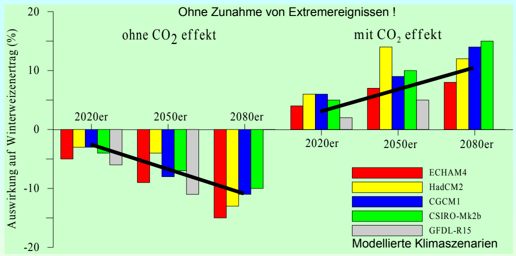
Remote Sensing Methods:

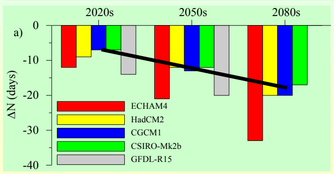
Improving knowledge on spatial variabilites of surface conditions

Below: Spatial soil varibilities (Hymap, Marchfeld)

Precision farming: Spatial yield distribution, winter wheat





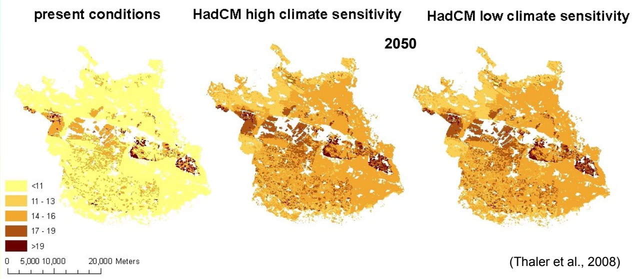


Crop model applications

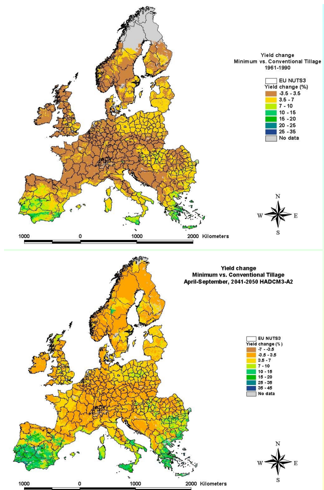
Climate change impacts on winter wheat yields in Austria

(Alexandrov and Eitzinger, 2001)

Increase of water stress
(simulated for spring barley - eastern Austria



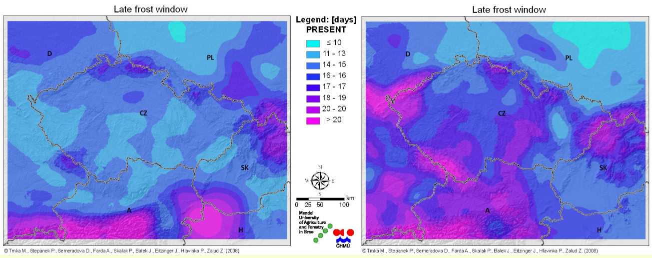
Spatial scale: 1:25000 digital soil map – 5 soil classes



Spring wheat yield change (%) between minimum and conventional tillage for baseline (1961-1990) and climate change scenario (2041-2050 HADCM3-A2) (Simota, 2009)

Difference between date of the last frost with the return probability 2 and 20 years

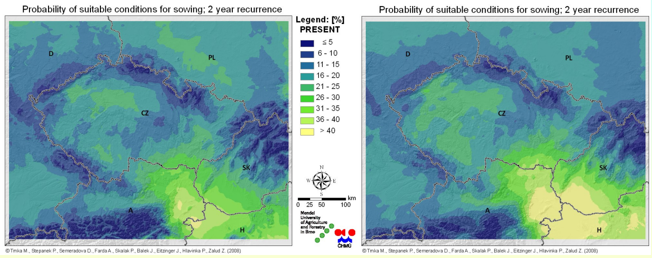
RCM - Frost risk (Agriclim)



Median = 14 days
Min = 6 days
Max = 38 days

Median = 16 days
Min = 7 days
Max = 33 days

RCM - Sowing conditons (early spring)



Median = 16%
Min = 0%
Max = 53%

Median = 16%
Min = 0%
Max = 60%

Potential deviations between crop models – simulated yield

MAIZE – Minimum Soil Cultivation

	Site A - 2003										Site A - 2004								
	T4	t2	Tt2	Tt4	T4P	t4P	Tt2P	Tt4P	P		T4	t2	Tt2	Tt4	T4P	t4P	Tt2P	Tt4P	P
DSSAT	-15.4	-10.5	-13.9	-15.8	-34.3	-32.2	-32	-37.6	-29.6		-24.9	-22.1	-23.9	-28.3	-25	-22.3	-23.7	-28.4	-19
EPIC	-8.5	4	-2.7	-5.4	-45.9	-44.3	-45.1	-47	-43.5		-6.2	4.6	-1.1	-2.1	-12.7	-3.1	-8.3	-9	-7.3
WOFOST	-15.3	-6.9	-11.1	-23.5	-66.7	-62.2	-64.8	-72.8	-55.3		-10.5	-5.2	-8.3	-16.9	-16.1	-11.1	-14	-22.4	-6
AQUACROP	-4.1	-3.7	-4.5	-5.6	-86.7	-86	-86.3	-86.8	-85.8		0.6	-1.9	-2.4	-2.8	-13.5	-11.8	-12.5	-13.3	-12.1
FASSET	-2	-2	-2	-5.1	-22.2	-22.2	-22.2	-24.4	-22.2		-4.8	-4.8	-4.8	-7.8	-5.8	-5.8	-5.8	-9.2	-0.6
HERMES	2	2	2	1.3	-26.2	-26.2	-26.2	-39.6	-35.1		3.9	3.9	3.9	-2.8	-3.7	-3.7	-3.7	-23.4	1.1
CROPSYST	-5.6	3.5	-1.7	-5.1	-11.1	-5.1	-8.6	-10.2	-7.4		-6.5	2.8	-1.2	-3.7	-15.5	-11.4	-13.6	-14.6	-13
mean	**-7**	**-1.9**	**-4.8**	**-8.5**	**-41.9**	**-39.7**	**-40.7**	**-45.5**	**-39.8**		**-6.9**	**-3.2**	**-5.4**	**-9.2**	**-13.2**	**-9.9**	**-11.7**	**-17.2**	**-8.1**
	Site B - 2003										Site B - 2004								
DSSAT	-3.5	-0.7	-2.9	-7.7	-54.3	-54.2	-54.8	-58.8	-50.9		-0.6	-0.6	-0.1	0	-15.8	-13	-14.4	-15.2	-14.2
EPIC	-8	-1.1	-4.6	-9.9	-66.9	-66.1	-66.5	-69.5	-63.2		-6	1.6	-2.5	-6	-16.5	-10.8	-14.1	-17.6	-11.1
WOFOST	-92.9	-8.1	-9.5	-13.6	-99.5	-99.3	-99.5	-99.9	-11.7		-18.8	-2.1	-2.7	-6.7	-22.1	-20.5	-20.7	-23.6	-4.8
AQUACROP	-4	-6.3	-7.8	-10.1	-77.1	-76	-76.5	-77.2	-75.8		-0.7	0.2	-0.3	-0.9	-43	-40.8	-41.8	-40.5	-40
FASSET	-2.9	-2.9	-2.9	-4.6	-26.1	-26.1	-26.1	-25.3	-23.9		-1.5	-1.5	-1.5	-1.1	-0.6	-0.6	-0.6	-0.4	1
HERMES	-6.3	-6.3	-6.3	-8.1	-69.3	-69.3	-69.3	-69.2	-69.8		6.3	6.3	6.3	7.2	13.2	13.2	13.2	14.4	6.5
CROPSYST	-7.4	-0.6	-5.2	-7.1	-11.6	-7.3	-10.1	-10.2	-9.4		-11.6	3.7	-4.4	-9	-27.8	-23.1	-25.8	-26.6	-24.9
mean	**-17.8**	**-2.7**	**-4.5**	**-7.8**	**-59.3**	**-58.2**	**-58.8**	**-60**	**-44.9**		**-4.6**	**1.2**	**-0.6**	**-2.2**	**-10.7**	**-8.4**	**-9.5**	**-10.5**	**-7.5**

Crop model applications – understanding uncertainties is crucial !

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Novi Sad, SERBIA

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H2020-TWINN-2015

Agrometeorology between applied and fundamental

Branislava Lalić

Faculty of Agriculture, University of Novi Sad, Serbia

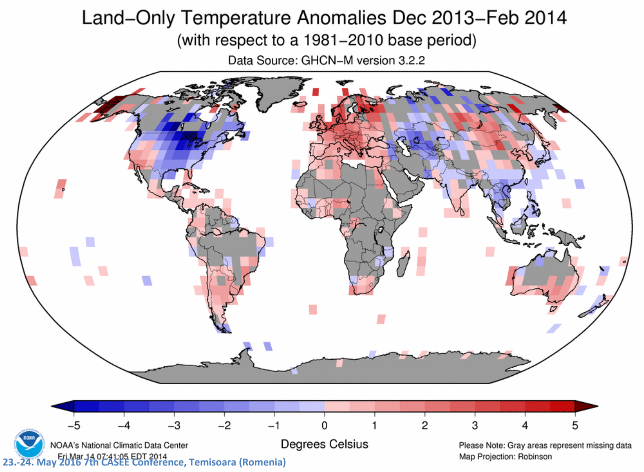
"Be very, very careful what you put into that head, because you will never, ever get it out".

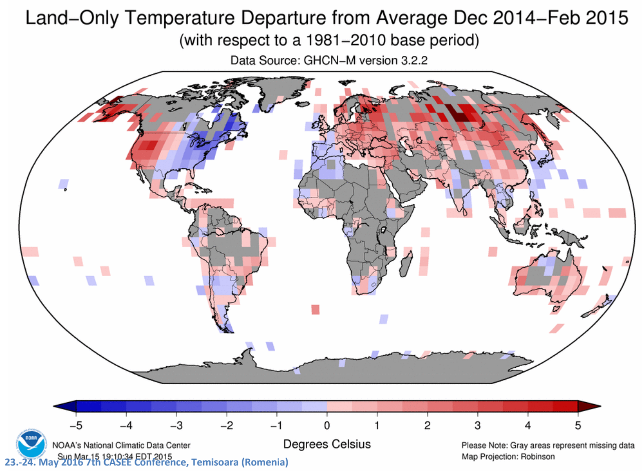
Thomas Cardinal Wolsey (1471-1530)

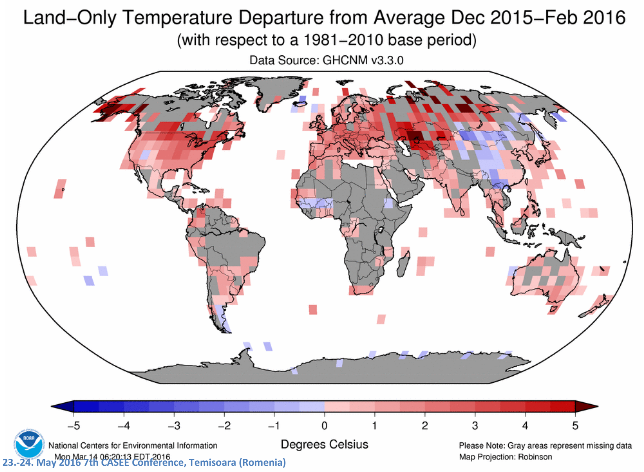
Agrometeorology is an interdisciplinary holistic science which is a real bridge between physical and biological sciences

Effects of CC, EWE, chronic undernourishment (805 million in the world 2012-2014 (FAO, 2014)) ...

Agrometeorology - inevitable element of the solution







OBSERVED CHANGES IN PHENOLOGY DYNAMICS

Region	Dates	Change (days)
Novi Sad	13.03.2015. 14.01.2016.	- 58
B a č k a Topola	19.03.2015. 20.01.2016.	- 58
Pančevo	12.03.2015. 15.02.2016.	- 26
Ruma	22.02.2015. 31.12.2015.*	- 53
Sombor	03.03.2015. 21.12.2016.*	- 73

GROWING PROBLEM

Shift in appearance of "four tillers detectable" - growing stage of winter wheat in Serbia (Source: PIS Serbia).

"Be very, very careful what you put into that head, because you will never, ever get it out".

Thomas Cardinal Wolsey (1471-1530)

OBSERVED CHANGES IN PHENOLOGY DYNAMICS

Region	Dates	Change (days)
Novi Sad	13.03.2015. 14.01.2016.	- 58
Bačka Topola	19.03.2015. 20.01.2016.	- 58
Pančevo	12.03.2015. 15.02.2016.	- 26
Ruma	22.02.2015. 31.12.2015.*	- 53
Sombor	03.03.2015. 21.12.2016.*	- 73

GROWING PROBLEM

Shift in appearance of "four tillers detectable" - growing stage of winter wheat in Serbia (Source: PIS Serbia).

23.-24. May 2016 7th CASEE Conference, Temisoara (Romenia)

"Be very, very careful what you put into that head, because you will never, ever get it out".

Thomas Cardinal Wolsey (1471-1530)

- Questions ⇒ No answers
- Discussions ⇒ No conclusions
- "Uncover" AgM – related misunderstandings and misconceptions
- "*EXPERIMENT-THEORY-PRACTICE*" – CONCEPT OF ALL TIMES
- AgM version of "The Hitchhiker's Guide to the Galaxy"

or

- "What ever modeler/data user should have in mind?"

MISUNDERSTANDINGS, MISCONCEPTIONS, LACK OF DATA REPRESENTATIVENESS ...

Often it looks like interdisciplinarity, it behaves like interdisciplinarity - but it is not:

- data used from nearest station – "purpose not included"

⇓

- satelite data

⇓

- BIG DATA issue

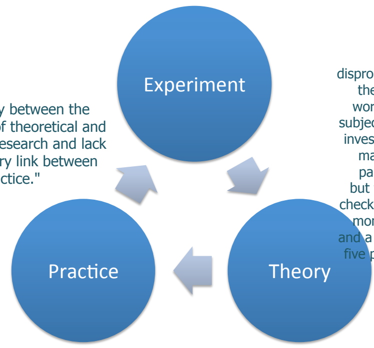
⇓

"... we are from atmospheric sciences. We had been working with **big data** from the beginning of time"

D.R. Fitzjarrald, personal communication

"*EXPERIMENT-THEORY-PRACTICE*", P.L. Kapitza

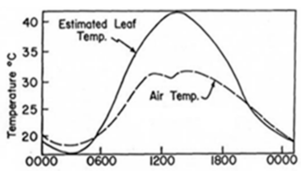
"... discrepancy between the development of theoretical and experimental research and lack of the necessary link between theory and practice."



"This is how the disproportion arises between the amount of theoretical work and the possibility of subjecting it to experimental investigation: a theoretician may well produce several papers per year, say four, but to do the experimental checking, a year or eighteen months is usually required and a group of, shall we say, five persons has to work on each."

AIR TEMPERATURE & HUMIDITY ⇄ PLANT TEMPERATURE & "HUMIDITY"

"The Hitchhiker's Guide to the Galaxy"

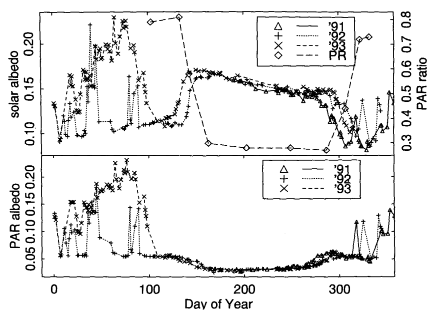


What is environmental temperature for "on-canopy" leaving organisms?

6

LAI ⇄ ALBEDO

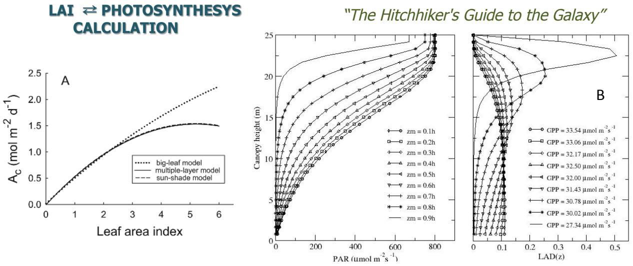
"The Hitchhiker's Guide to the Galaxy"



Moore, K. E., D. R. Fitzjarrald, R. K. Sakai, M. L. Goulden, J. W. Munger, S. C. Wofsy, 1996: Seasonal Variation in Radiative and Turbulent Exchange at a Deciduous Forest in Central Massachusetts, *Journal of Applied Meteorology*, 35 (1), 122-134.

LAI ⇄ PHOTOSYNTHESYS CALCULATION

"The Hitchhiker's Guide to the Galaxy"



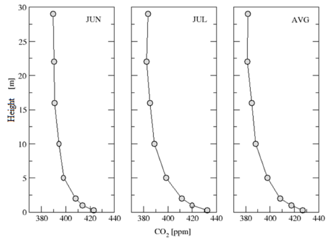
Predictions of canopy-level CO_2 assimilation rate (Ac) as a function of LAI (panel A) and GPP as a function of LAD (panel B). Ac was predicted using the biochemical models of Farquhar and von Caemmerer (1982) coupled to three different types of canopy flux models; a big-leaf model, a multiple layer model, and a sun/shade big-leaf model.

Monson, R., Baldocchi, D., 2014: *Terrestrial Biosphere-Atmosphere Fluxes*. Cambridge University Press, pp. 518.
Firanj, A., Lalic, B., Podrascanin, Z., (2014) The Impact of Forest Architecture Parameterization on GPP simulations. *Theoretical and Applied Climatology*, 121, 3, 529-544

TURBULENT TRANSFER OF CO2 ⇄ NEE

"The Hitchhiker's Guide to the Galaxy"

The net exchange of CO_2 between the atmosphere and the canopy can be formulated as the sum of all sources and sinks of this gas within the inside the layer in which turbulent transport occurs.



$$\mathrm{NEE} = \int_0^{z_r} \frac{\partial S_{c,z}}{\partial t} dz$$

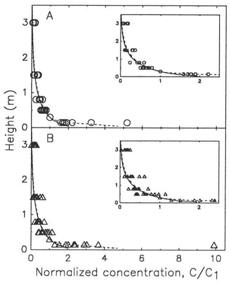
$$\mathrm{NEE} = \left(\overline{wc}\right)_{z_r} + \int_0^{z_r} \frac{\partial C}{\partial t} dz + \int_0^{z_r} w \frac{\partial C}{\partial z} dz + \int_0^{z_r} u \frac{\partial C}{\partial x} dz$$

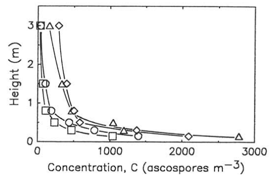
turbulent transport — change in stored gas — concentration flux in vertical and horizontal direction non turbulent

TURBULENT DIFUSION ⇄ Venturia inaequalis spatial distribution

"The Hitchhiker's Guide to the Galaxy"

$$U(z)\frac{\partial C(x,z)}{\partial x} = \frac{\partial}{\partial z}\left[K(z)\frac{\partial C(x,z)}{\partial z} + v_S \cdot C(x,z)\right] - G(z)\cdot C(x,z)$$





Aylor, D.E., 1995: Vertical Variation of Aerial Concentration of *Venturia inaequalis* Ascospores in an Apple Orchard, Ecology and Epidemiology, Vol. 85, No. 2, 175-181.

Effects of CC, EWE, chronic undernourishment (805 million in the world 2012-2014 (FAO, 2014)) ...

... inevitable element of the solution

- How much of current results is already applied?
- Are we aware about limitations and/or weaknesses of our results?
- Are we aware about real or potential users of our results?

"*Be very, very careful what you put into that head, because you will never, ever get it out*".

Thomas Cardinal Wolsey (1471-1530)

Questions for audience

- how much of our results is "in use"?
- why policy makers and users are often not interested?
- how much we go public?
- are we aware about real/potential users of our results?
- are we aware about limitations and/or weaknesses of our results?
- how much do we know about data which we are using for modeling, to make conclusion and decisions?

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DISPAA
DIPARTIMENTO DI SCIENZE DELLE PRODUZIONI AGROALIMENTARI E DELL'AMBIENTE

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27 June – 01 July 2016
Novi Sad, SERBIA

Serbia for Excell
H2020-TWINN-2015

Agrometeorological models: fundamentals

A. Dalla Marta, F. Natali, S. Orlandini,

Department of Agrifood Production and Environmental Sciences
University of Firenze, Italy

What is a models?

A model is a simplified representation of a system.
A system is a well-defined part of the real world.

In agronomy a system can be:

- a crop with all its organs (roots, stems, leaves) and its processes and mechanisms (growth, development, photosynthesis, transpiration, etc.)
- The development of a pathogen and its negative effects on a crop

What is a models?

The construction of a model consists in the identification of a series of mathematical equations by which it is possible to reproduce in the most faithful possible way the behaviour of the examined system

The main advantage is related to the possibility of applying models under agricultural conditions, cultivation and management different from those where models were developed

Why to use models?

Models and measurements…

"Nobody believes in simulation models except their developers… Everybody believes in experimental data except who collected them"

(Gaylon S. Campbell)

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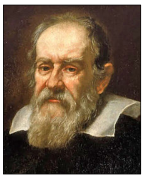
The scientific method…



Galileo Galilei (1564 – 1642)

1. Make observations
2. Collect information
3. Formulate hypotheses about why things are the way they are
4. Deriving predictions
5. Carrying out experiments based on those predictions

What does it mean?

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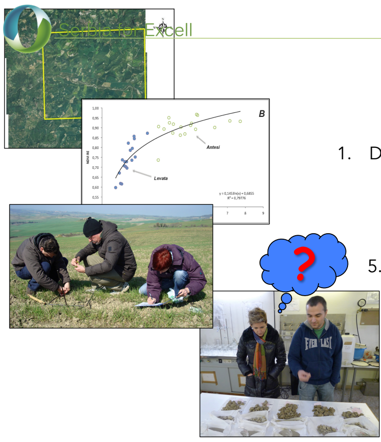

Make measurements:

1. Determine sample size and schemes
2. Collect samples
3. Store samples
4. Analyse samples
5. Record data in a meaningful way
6. Process data
7. Interpret data

In each of these steps, it is possible to make mistakes

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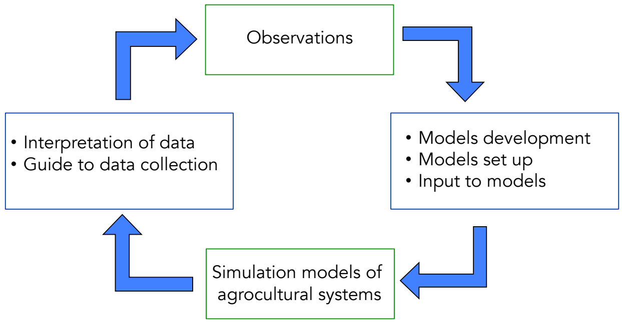
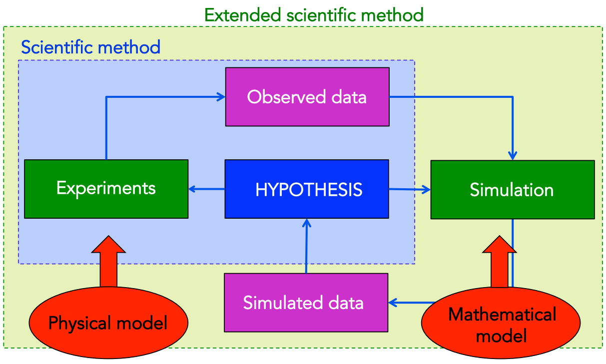
The reality

- Need of quick information (near real time) about what is happening in a given situation or what will change in the system as a result of perturbative events (scenario analysis)
- Limited resources for direct observations (especially on regional scale assessments)

Are then models substitutes of direct observation?



The answer is obviously NO



Simulation models can be considered a tool to extend the scientific method

Why to use models to study the reality?

- The states of the system may not be observable, if not with extreme difficulty
- Traditional experiments can damage the system
- The conditions that you want to test may not be practicable
- The time required for experiments can be very long, or experiments can be very expensive
- The number of conditions to be evaluated can be very high

Sectors of application

✓ Crop growth and development
✓ Crop productivity
✓ Water balance
✓ Protection from environmental adversities (extreme events, drought, etc.)
✓ Protection from biological adversities (pests and diseases)
✓ Climate change
✓ Generation of missing data
✓ Spatial and temporal interpolation

General benefits

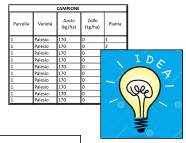
- Better understanding of physical and biological processes
- Organization of the available knowledge and identification of gaps and future research objectives
- Manipulations on the real system to test hypotheses about how it works
- Evaluation of possible external interventions to change the behaviour of the system
- Application as a didactic tool to illustrate the structure and behavior of the system

General critics

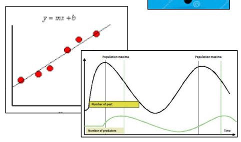
- Anticipation of operational application procedures
- Limited procedures of verification and validation
- Lack of input
- Excessive expectations in respect of the benefits, especially in relation to an application without the control by experts in the field

Models classification

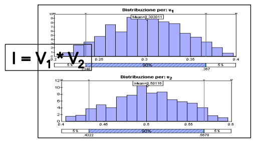
Empirical o descriptive (based on collected data)
Mechanistic or explicative (developed from a theory)



Static (fixed relations) // Dynamic (evolution in time)



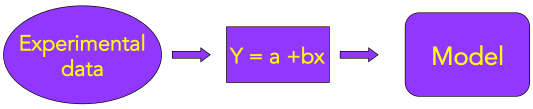
Deterministic (single result: fixed input)
Stochastic (probabilities: variable input)



Empirical models

Empirical models describe in a simplified way the behaviour of a crop.

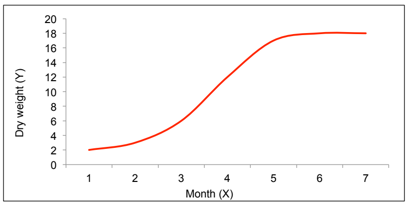
The development of an empirical model is based on the identification, starting from experimental data, of one or more mathematical equations able to represent the process examined



Empirical models

A simple empirical model is the exponential mathematical function that describes the increase in dry weight of a plant in time

This function is based on the simple observation that, up to a certain stage of the biological cycle, the relative growth rate assumes a constant value over time



It describes the process (growth), but does not explain any of the physiological mechanisms that govern it

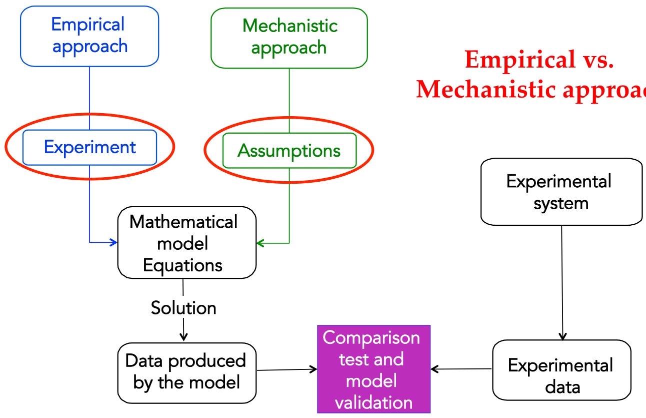
Mechanistic models

Mechanistic models describe and explain a specific phenomenon based on the fundamental mechanisms that govern the functioning of the system

For example, the increase of the dry weight can be described by a series of more complex functions, each of which takes account of smaller sub-processes, such as the influence of the ecophysiological characteristics of the species on light interception, on photosynthetic process, on the production of assimilates and, therefore, on the increase of dry weight

The resulting pattern is quite complex, but (theoretically) able to predict the growth of a plant regardless the environmental conditions

Empirical vs. Mechanistic approach



Static and dynamic models

Static models: they represent relationships between variables that do not change with time, and then you know the final value only and not the trend over time (e.g. *regression models*)

Dynamic models: contain the time as an explicit variable. Describe the way in which the system changes over time (e.g. *disease simulation models*)

Deterministic and stochastic models

Deterministic models: make a prediction providing as output a numeric value without giving any measure of its probability distribution. The input variables assume fixed values. It does not take into account the uncertainty associated with the input variables

Stochastic models: (stochastic = due to chance, random) take into account the variations (causal or not) of the input variables, and then provide results in terms of "probability"

It is important to emphasize that what differentiates the deterministic models by stochastic ones is that in the latter is taken into account the variability of the input data.

Conceptual phase
Objectives formulation
Limits definition
Conceptualization of the system and identification of elements

Understanding phase
Real data gathering (literature, experiments)
Model formulation
Model verification (comparison with data used for its development)

Summary phase
Validation (against independent data)
Sensitivity analysis
Simplification
Formulation of decisional rules for crop management
Program implementation

Application of a simulation model

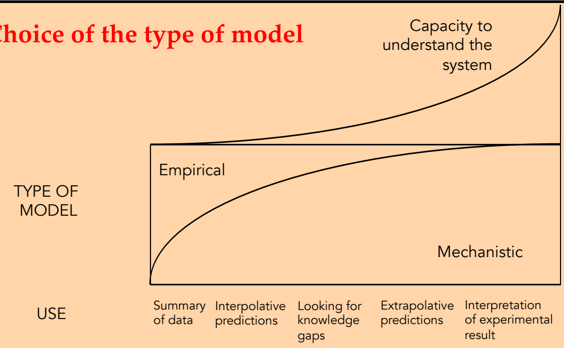
1. Choice of the type of model
2. Identification and quantification of the processes to simulate
3. Calibration
4. Assessment of potentials (validation and sensitivity analysis)
5. Application

1. Choice of the type of model

Whatever the specific application for which the use of a simulation model is required, it is necessary:

1. To clearly identify goals (what my model should exactly do?) and the conditions of application (scale of application, data availability, etc.)
2. To derive a quantitative criterion for assessing the different models according to their suitability
3. Use the criterion obtained to order models
4. Choose the most suitable model for the specific application (the best model for that goal, and in those conditions)
5. Critically use the model chosen

1. Choice of the type of model



1. Choice of the type of model

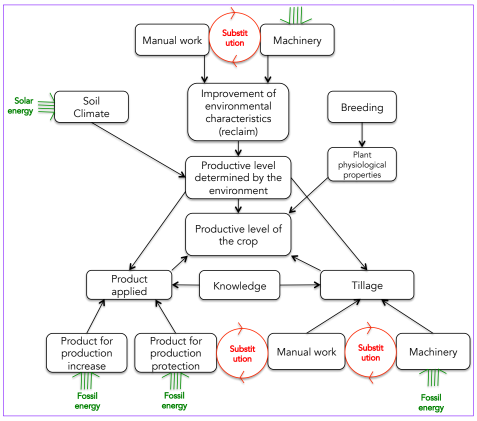
Data availability (development, validation and application)

- ✓ Model development:
  Measurements of the effect of environmental variables on the considered process (growth, development, water balance)
- ✓ Model validation:
  Experimental independent data on the single processes considered by the model (photosynthesis, biomass partitioning)
- ✓ Model application:
  Data on crop (phenology, growth), on agricultural techniques (sowing date, chemical application) and on the environmental conditions (meteo)

2. Identification and quantification of the processes to simulate

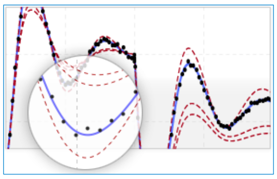
A model must consider the conditions that influence the process tested:

- Environmental factors
- Plant physiology
- Pathogen
- Applied products
- Cropping techniques



3. Model calibration

Procedure through which one or more series of experimental data is used to formulate the model, to compare the data obtained with the experimental reality, to eventually reformulate the model structure or adjust some parameters.



4. Assessment of model potentials

Validation

Procedure by which you compare the simulated data from the model with experimental data NOT used in its development to identify the accuracy and precision of estimates

Validation procedures:

1. Subjective evaluation: distinction by expert between simulated and observed data

2. Visual techniques: graphic comparison between simulated and observed data

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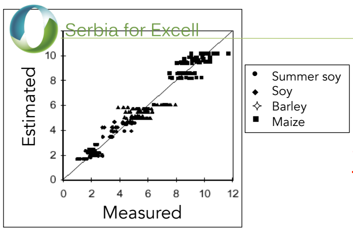
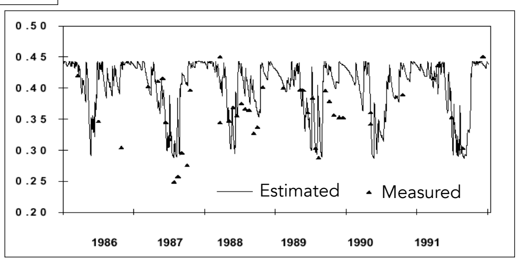
Validation *(visual techniques)*





Model's performance indices

- Mean relative error $MRE = \sum_{i=1}^{n} (y_i - y_{st\,i})$
- Mean absolute error $MAE = \sum_{i=1}^{n} |y_i - y_{st\,i}|$
- Mean square error $MSE = \sqrt{\frac{\sum_{i=1}^{n} (y_i - y_{st\,i})^2}{n}}$
- Determination coefficient $R^2 = 1 - \frac{\sum_{i=1}^{n} (y_i - y_{st\,i})^2}{\sum_{i=1}^{n} (y_i - y_M)^2}$

Calibration and validation

DIFFERENT DATASETS FOR CALIBRATION AND VALIDATION

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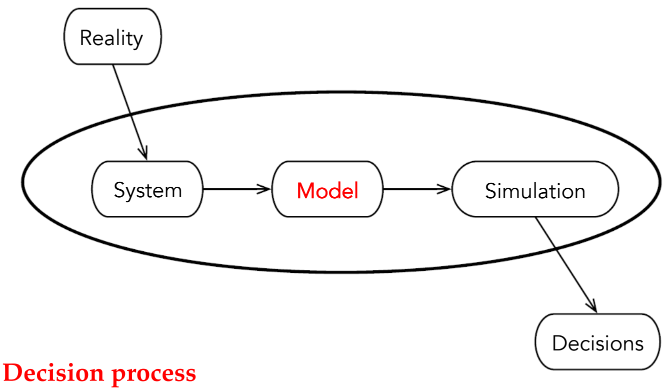
Sensitivity analysis

Procedure by which you can evaluate the model's response to changes in environmental and climatic parameters required by the model itself

	Change (%)									
Year	Temperature					Relative humidity				
	-10	-5	0	5	10	-10	-5	0	5	10
1995	9,29	12,1	16,85	21,46	13,54	1,61	6,79	16,85	37,04	73,87
1996	1,06	2,36	2,26	2,4	4,66	0,36	0,68	2,26	12,22	56,91
1997	4,47	5,5	3,04	3,4	4,59	0,57	2,64	3,04	7,99	16,51
1998	4,18	5,1	3,6	4,94	5,13	0,34	1,4	3,6	22,09	36,87

5. Application

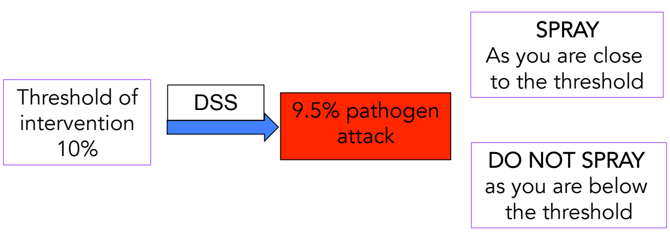
- Management of protection techniques
- Long term management
- Impact analysis and production estimates
- Predictions for food production
- Breeding
- Sustainability of agricultural systems
- Climate change
- Insurances



Decision process

Interpretation

The way the various solutions to a problem are presented affects the strategy that will be used; for example, in a model (or DSS) for crop protection the way with which the simulated degree of attack is communicated can affect the behaviour of the farmer



Sources

- Confalonieri Roberto, Di.Pro.Ve. – University of Milano
- Simone Orlandini, DiSPAA – University of Firenze