Crop simulation models evaluation

Gianni Bellocchi

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Grassland Research Ecosystem Unit - French National Institute for Agricultural Research
Clermont-Ferrand, France

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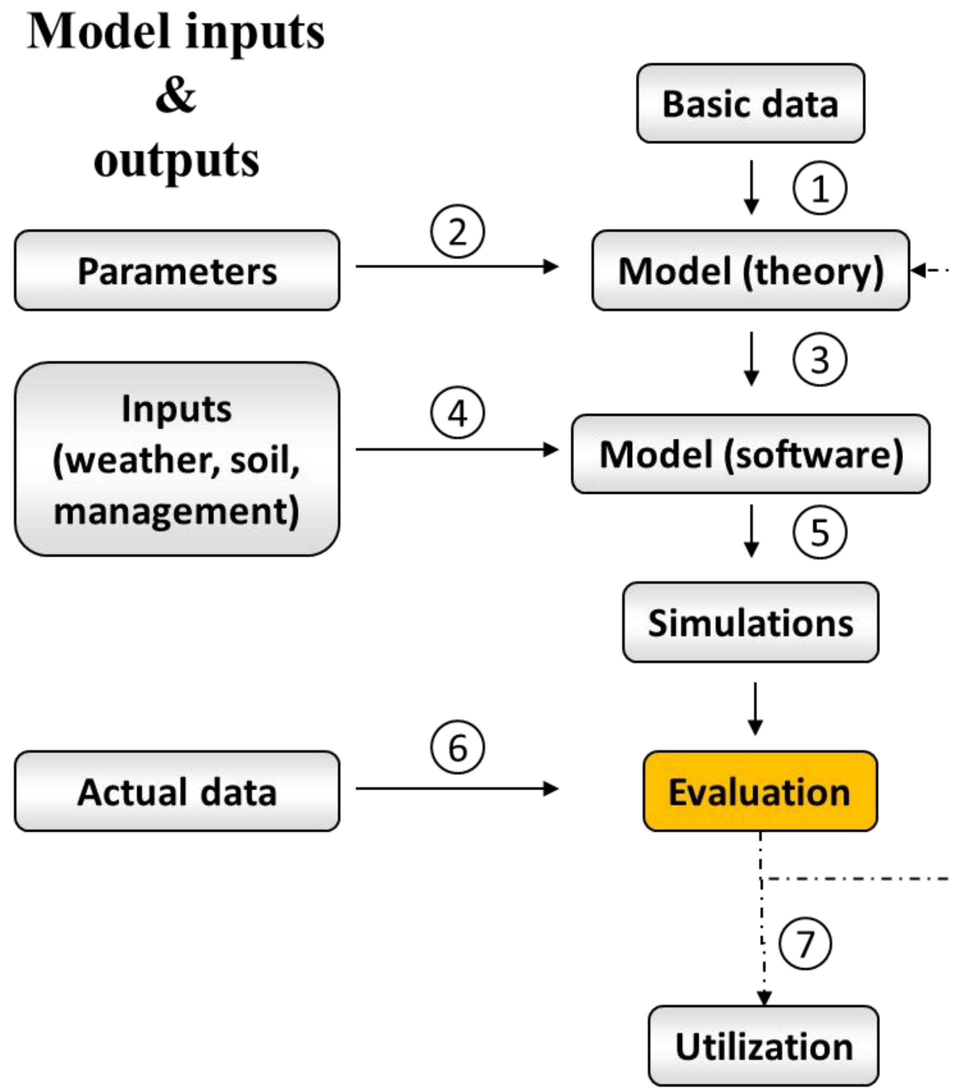
Sassari (Itay)

Agroecological system and modelling process

Actual system

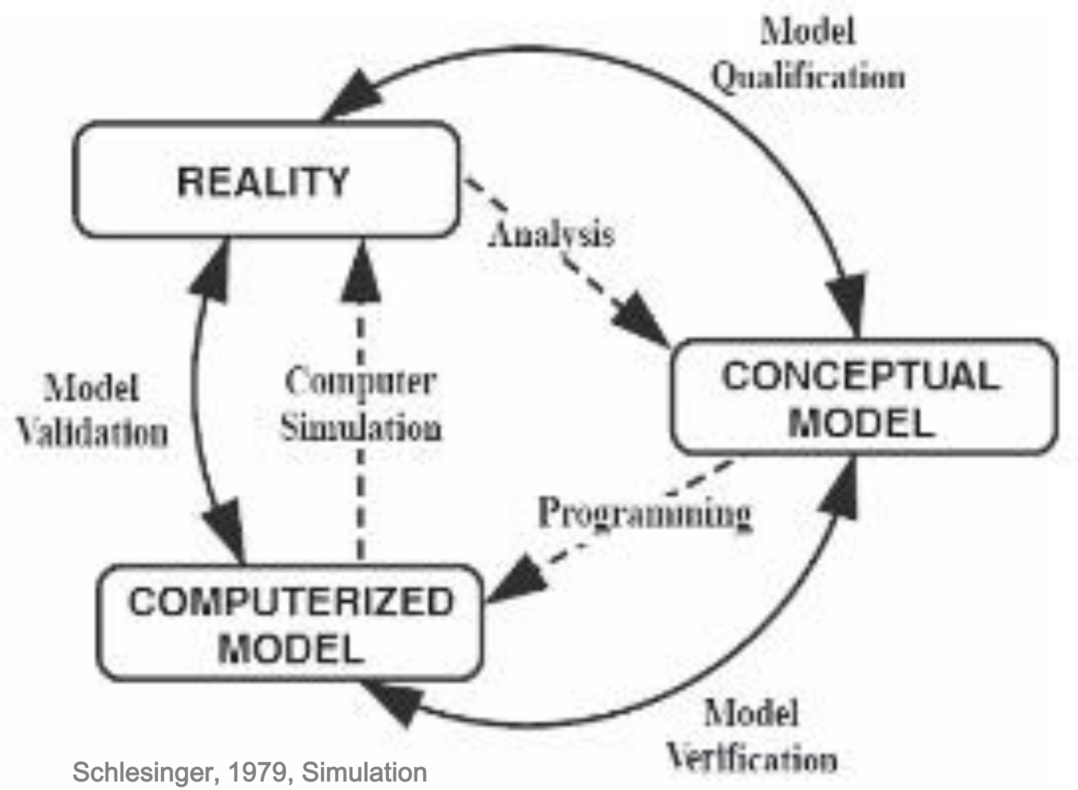


Modelling flow

Model evaluation

Model evaluation (validation + verification):

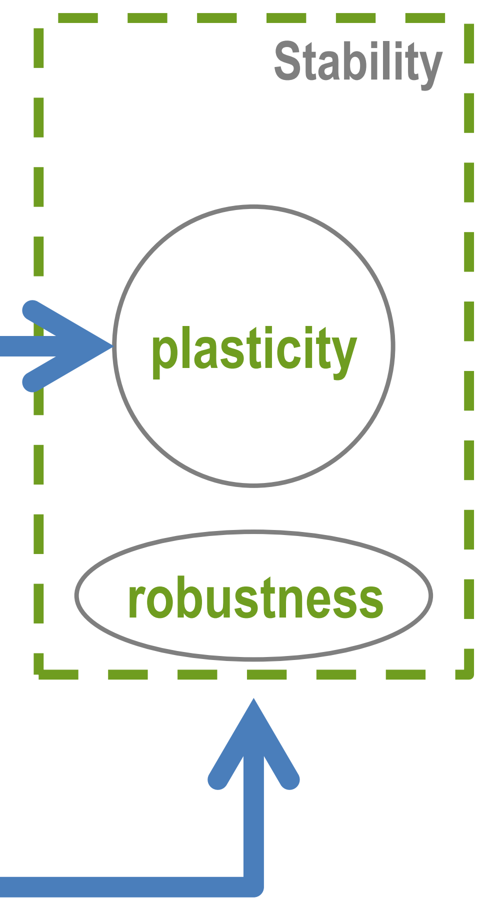
action in which the quality of a mathematical model for specific objectives is established



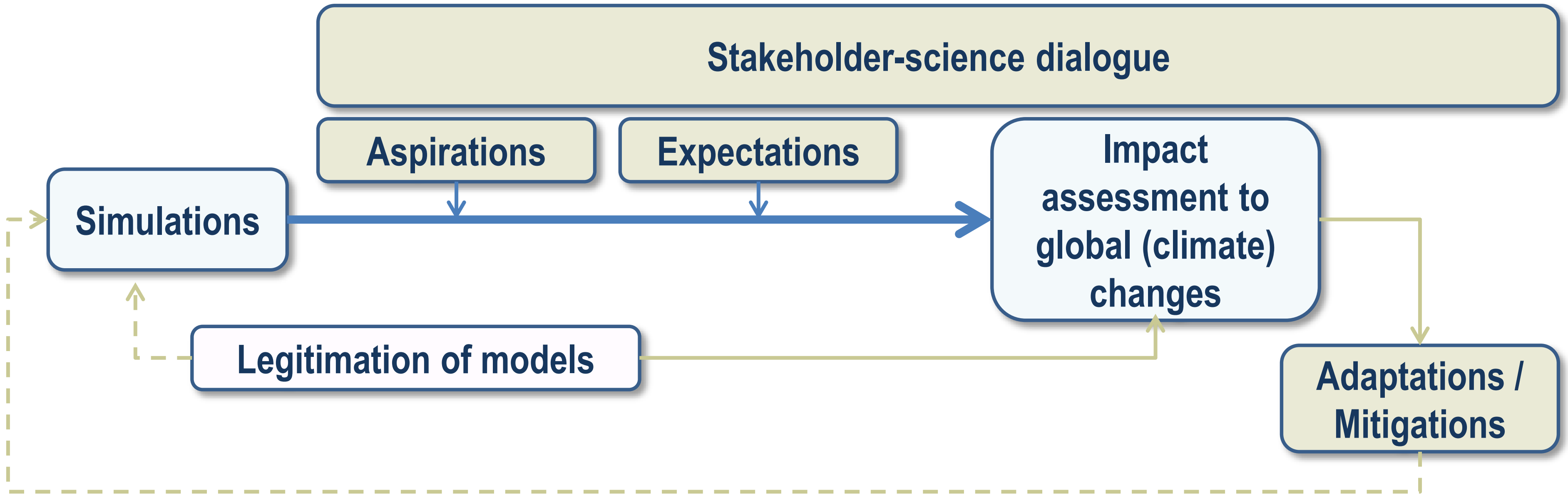
Schlesinger, 1979, Simulation

Model evaluation components

- Sensitivity analysis
- Uncertainty analysis
- Parameterization (calibration)
- Performance (validation)



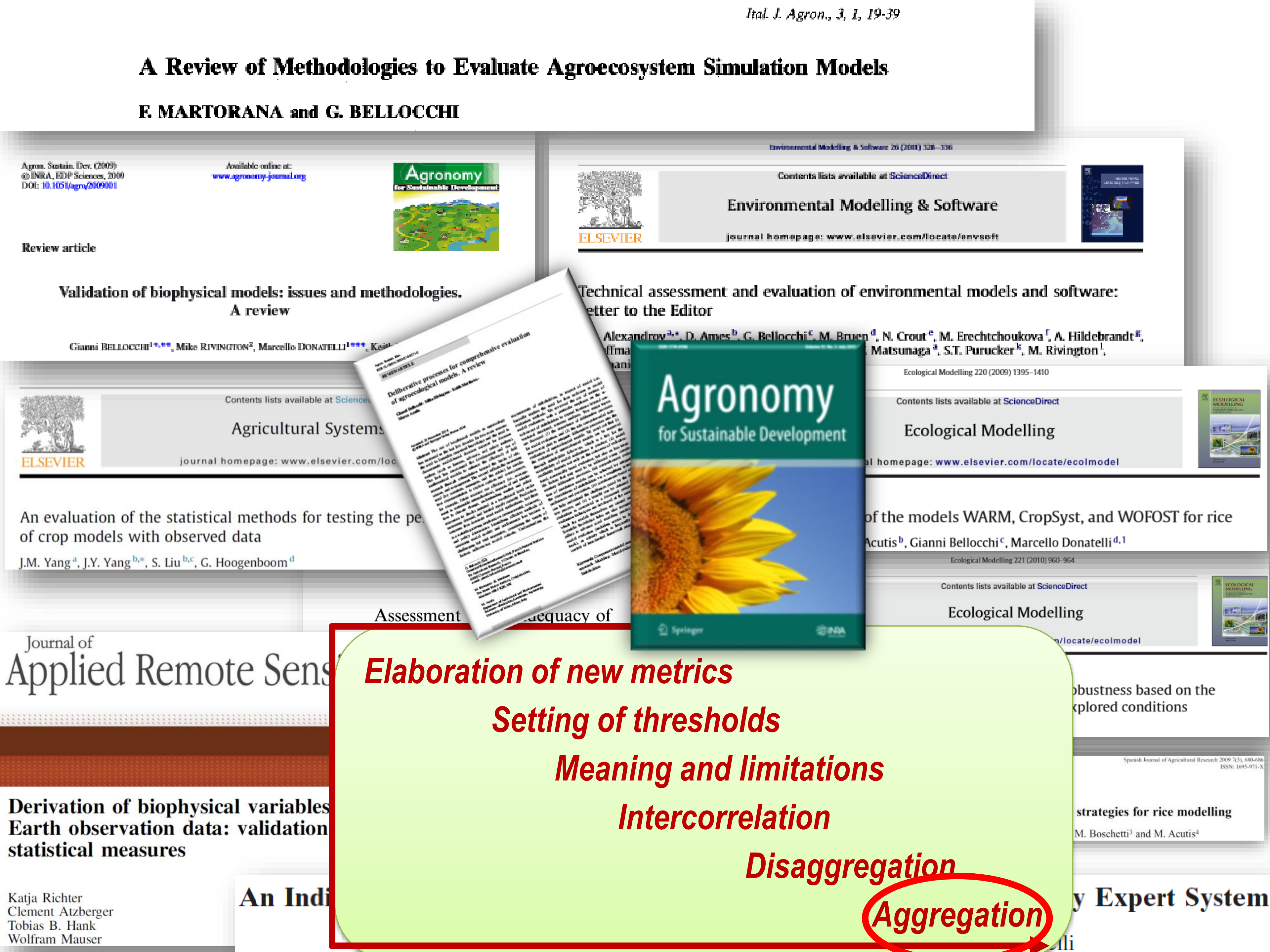
Deliberative process in model-based climate change studies



Bellocchi et al. (2006)

Rivington et al. (2007)

Bellocchi et al. (2015)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statistical measures
Katja Richter
Clement Atzberger
Tobias B. Hank
Wolfram Mauser
An Indi
y Expert System
Elaboration of new metrics
Setting of thresholds
Meaning and limitations
Intercorrelation
Disaggregation
Aggregation

Some metrics

difference-based metrics

simple

$$CRM = \frac{\sum_{i=1}^{n} O_i - \sum_{i=1}^{n} P_i}{\sum_{i=1}^{n} O_i}$$

absolute

$$MAE = \frac{\sum_{i=1}^{n} |P_i - O_i|}{n}$$

squared

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n} (P_i - O_i)^2}{n}}$$

non-parametric

$$MdAE = \text{median}_{i=1,\dots,n} |P_i - O_i|$$

association-based metrics

$$r = \frac{\sum_{i=1}^{n} (P_i - \bar{P}) \cdot (O - \bar{O})}{\sqrt{\sum_{i=1}^{n} (P_i - \bar{P})^2 \cdot \sum_{i=1}^{n} (O_i - \bar{O})^2}}$$

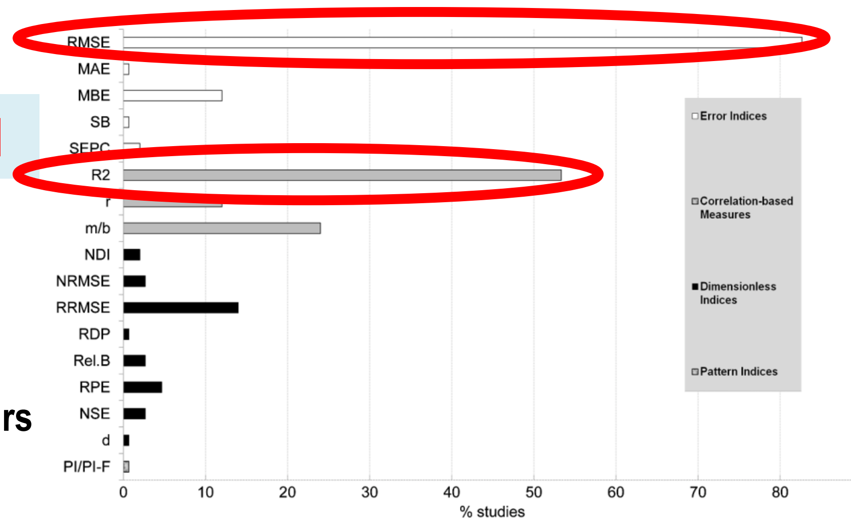
$r^2, slope, intercept$

combined

$$EF = 1 - \frac{\sum_{i=1}^{n} (P_i - O_i)^2}{\sum_{i=1}^{n} (O_i - \bar{O})^2}$$

$$d = 1 - \frac{\sum_{i=1}^{n} (P_i - O_i)^2}{\sum_{i=1}^{n} \left(|P_i - \bar{O}| + |O_i - \bar{O}|\right)^2}$$

P = predicted; O = observed; i = i^{th} O/P pair; n = number of O/P pairs



Richter et al. (2012)

Setting of thresholds

Performance measure	Unit	Value range and purpose	Reliability criteria
Coefficient of determination (**R^2**) of the linear regression estimates versus measurements	dimensionless	0 (absence of fit) to 1 (perfect fit): the closer values are to 1, the better the model	> 0.8
Willmott (1982) index of agreement (**d**)	dimensionless	0 (absence of agreement) to 1 (perfect agreement): the closer values are to 1, the better the model	> 0.8
Mean absolute error over the mean of the measured values (**MAE(%)**)	%	0 (optimum) to positive infinity: the smaller MAE(%), the better the model performance	< 20

De Jager (1994)

Key issues and factors

Key validation issues	Major factors to investigate				
	Modelling objective	Model inputs	Model outputs	Model structure	Modelling conditions
Validation purpose	X		X		X
Robustness of results			X		X
Interpretation of phenomena		X	X	X	
Model comparison				X	
Model predictions	X		X		X
Model complexity		X	X	X	
Data accuracy		X	X		
Time histories			X		

Bellocchi et al. (2010)

Fuzzy-logic based indicators

Model Quality Indicator (MQI_s) → MQI_s

Agreement

expert weight	Correlation coefficient (*R*) F Partial U ≥ 0.90 ↔ ≤ 0.70	Index of agreement (*d*) F Partial U ≥ 0.90 ↔ ≤ 0.70	Probability of equal means (*P(t)*) F Partial U ≥ 0.10 ↔ ≤ 0.05
0.00	F	F	F
0.20	F	F	U
0.60	F	U	F
0.80	F	U	U
0.20	U	F	F
0.40	U	F	U
0.80	U	U	F
1.00	U	U	U

membership function
$S[x; a = \min(F, U); b = \max(F, U)]$

membership function
$S[x; a = \min(F, U); b = \max(F, U)]$

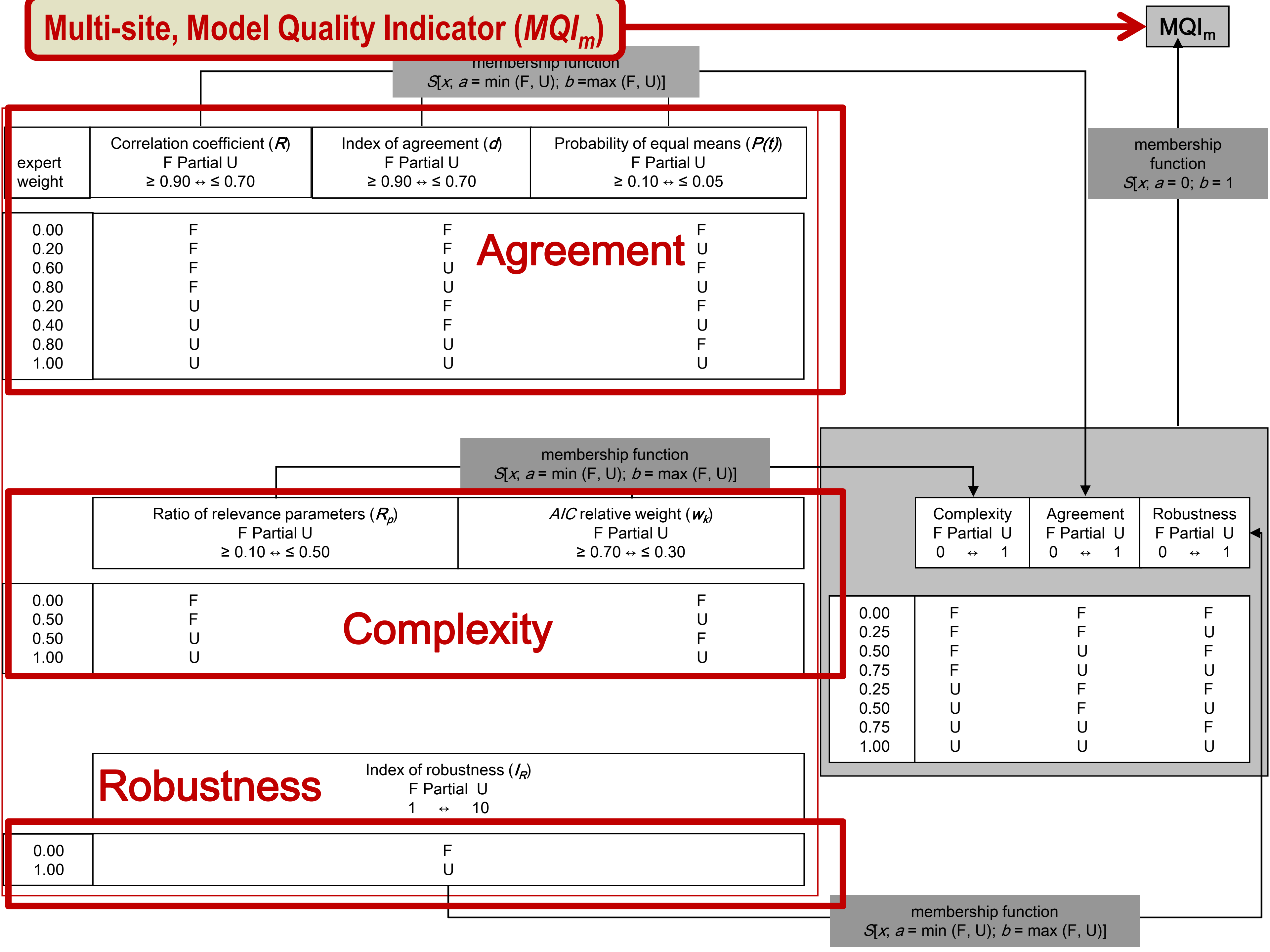
Complexity

	Ratio of relevance parameters (R_p) F Partial U ≥ 0.10 ↔ ≤ 0.50	*AIC* relative weight (w_k) F Partial U ≥ 0.70 ↔ ≤ 0.30
0.00	F	F
0.50	F	U
0.50	U	F
1.00	U	U

Complexity F Partial U 0 ↔ 1	Agreement F Partial U 0 ↔ 1	
F	F	0.00
F	U	0.75
U	F	0.25
U	U	1.00

membership function
$S[x; a = 0; b = 1]$

MQI_s



Multi-site, Model Quality Indicator (MQI_m)
MQI_m
membership function
$S[x; a = \min(F, U); b = \max(F, U)]$
membership function
$S[x; a = 0; b = 1]$
expert weight
Correlation coefficient (R)
F Partial U
≥ 0.90 ↔ ≤ 0.70
Index of agreement (d)
F Partial U
≥ 0.90 ↔ ≤ 0.70
Probability of equal means (P(t))
F Partial U
≥ 0.10 ↔ ≤ 0.05
0.00 F F F
0.20 F F U
0.60 F U F
0.80 F U U
0.20 U F F
0.40 U F U
0.80 U U F
1.00 U U U
Agreement
membership function
$S[x; a = \min(F, U); b = \max(F, U)]$
Ratio of relevance parameters (R_p)
F Partial U
≥ 0.10 ↔ ≤ 0.50
AIC relative weight (w_k)
F Partial U
≥ 0.70 ↔ ≤ 0.30
0.00 F F
0.50 F U
0.50 U F
1.00 U U
Complexity
Robustness
Index of robustness (I_R)
F Partial U
1 ↔ 10
0.00 F
1.00 U
Complexity
F Partial U
0 ↔ 1
Agreement
F Partial U
0 ↔ 1
Robustness
F Partial U
0 ↔ 1
0.00 F F F
0.25 F F U
0.50 F U F
0.75 F U U
0.25 U F F
0.50 U F U
0.75 U U F
1.00 U U U
membership function
$S[x; a = \min(F, U); b = \max(F, U)]$

Robustness of a model

A **robustness measure** would account for model performance stability over a wide range of conditions (single site versus multiple sites)

How the variability of model performance can be quantified with the variability of conditions?

Index of robustness

$$I_R = \frac{\sigma_{EF}}{\sigma_{SAM}}$$ (0, best; +∞, worst)

Modelling efficiency

$$EF = 1 - \frac{\sum_{i=1}^{n}(P_i - O_i)^2}{\sum_{i=1}^{n}(O_i - \bar{O})^2}$$ (-∞, worst; 1, best)

Synthetic Agro-Meteorological Indicator

$$SAM = \frac{Rain - ET_0}{Rain + ET_0}$$ (-1, +1)

Confalonieri et al. (2010)

Synthetic indicators

Aggregation rules:
fuzzy-logic based weighing system

I. Agreement

- Correlation coefficient
- Index of agreement
- Probability of equal means

Non-dimensionality

Lower and upper bounding

(best) 0 – 1 (worst)

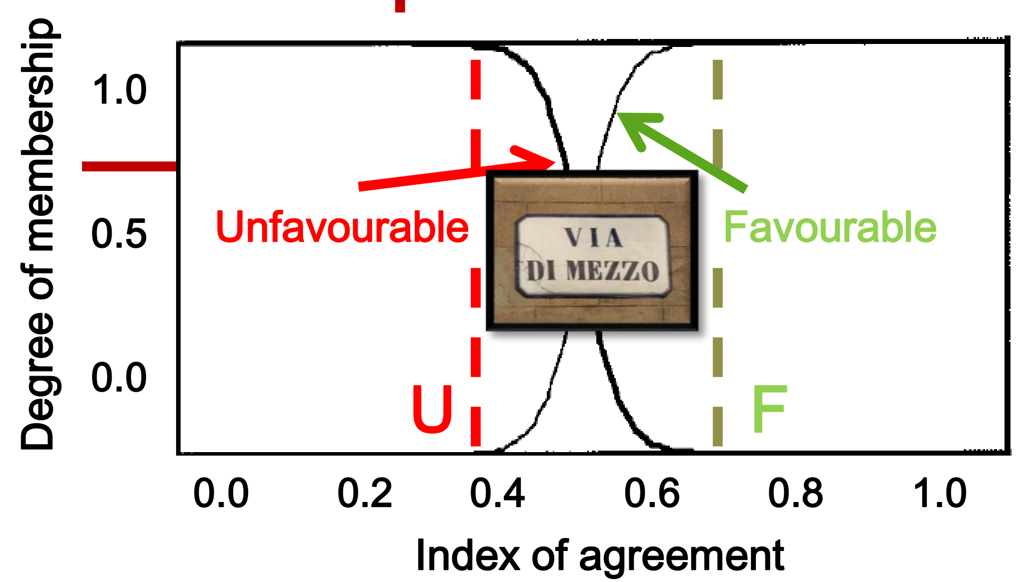
II. Complexity

- Ratio of relevant parameters
- Parameters-agreement criterion

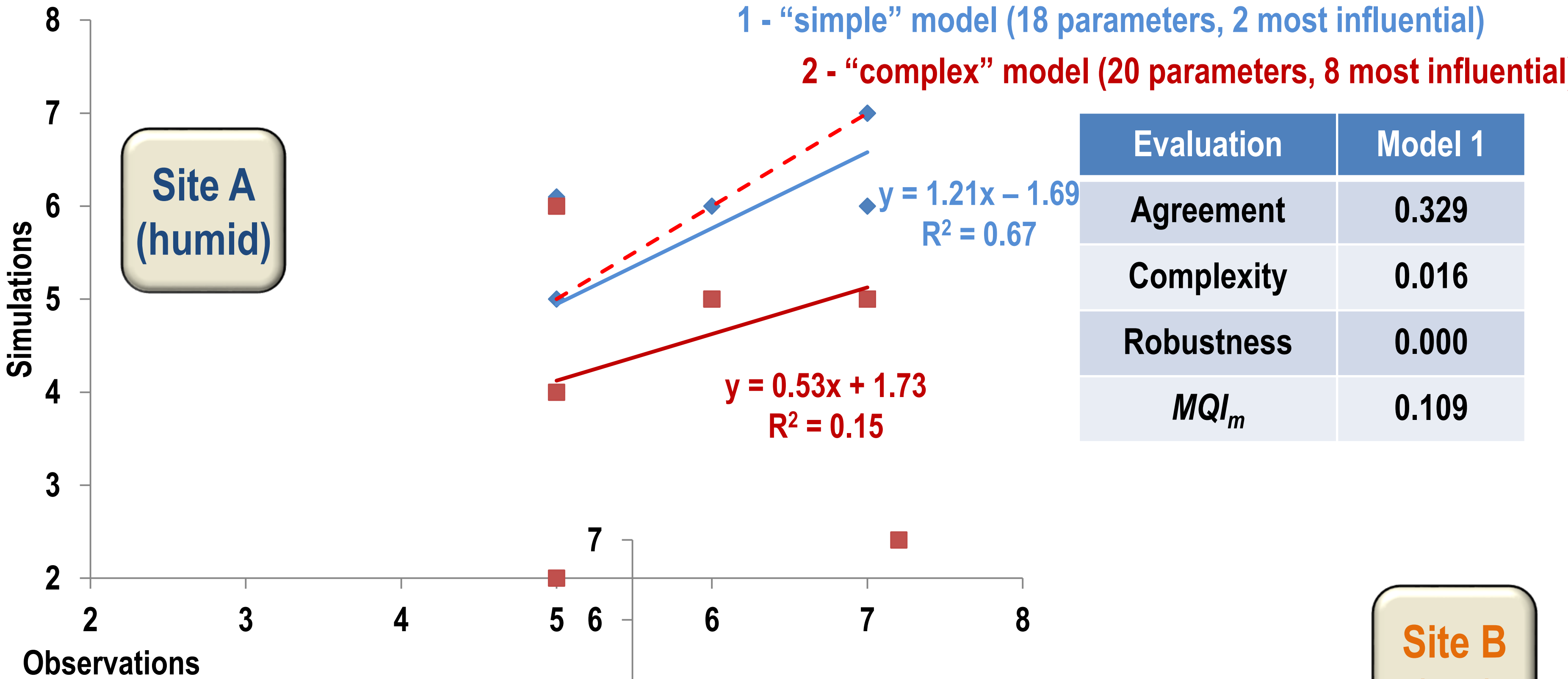
Model Quality Indicator

III. Stability (robustness)

- Index of robustness

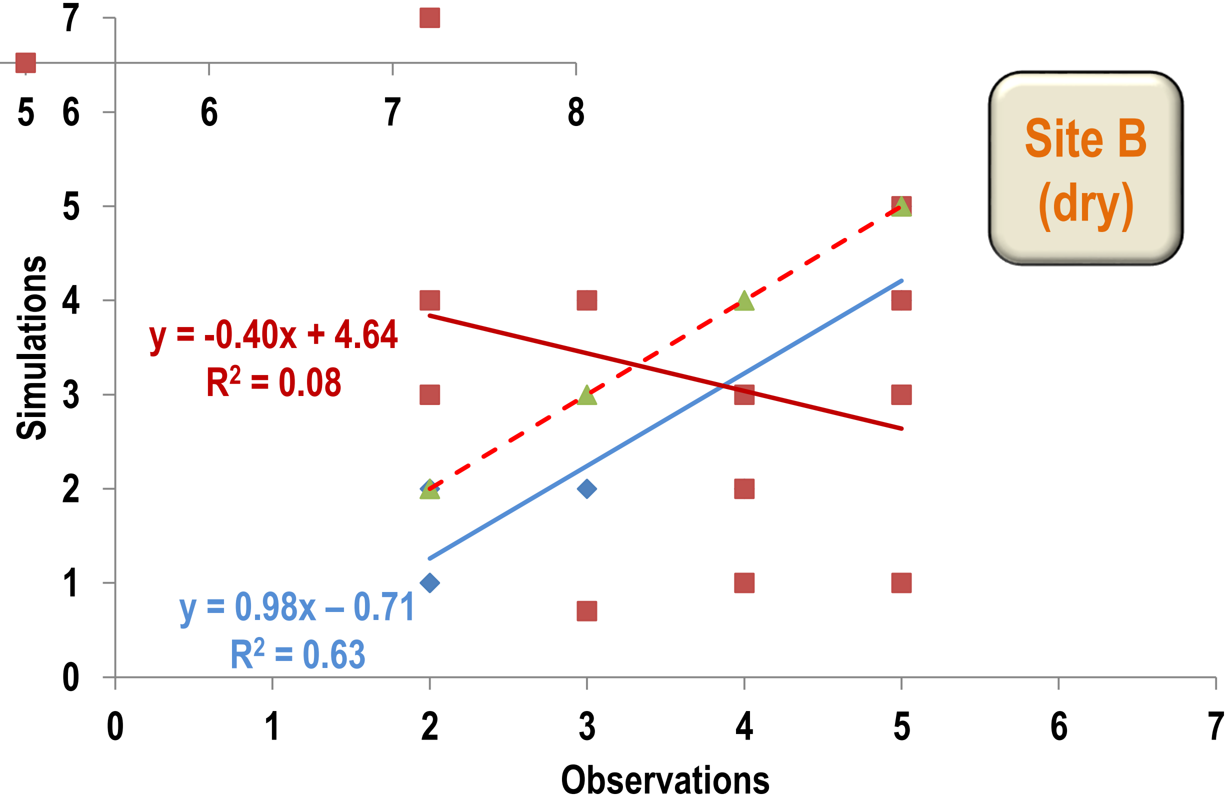


Hindrances to overcome:
thresholds and weights



Evaluation	Model 1
Agreement	0.329
Complexity	0.016
Robustness	0.000
MQI_m	0.109

Evaluation	Model 2
Agreement	0.800
Complexity	0.500
Robustness	0.006
MQI_m	0.556



Rice simulations:

above-ground biomass at maturity

Three models: CropSyst (simple), WARM (intermediate), WOFOST (complex)

MQI_s	M1	M2	M3
C. d'Agogna	**0.0313**	0.1250	0.2174
Vercelli	0.1070	**0.0853**	0.1372
Mortara	0.2188	**0.0000**	0.2174
Rosate	**0.0313**	0.2284	0.2388
MQI_m	**0.0750**	0.1940	0.3356

MSE	M1	M2	M3
C. d'Agogna	3.26	**1.86**	2.42
Vercelli	2.93	**1.35**	1.57
Mortara	1.66	**0.84**	0.94
Rosate	**0.97**	**4.96**	**6.75**

AIC	M1	M2	M3
C. d'Agogna	**34**	37	**79**
Vercelli	**33**	34	**73**
Mortara	**26**	28	**67**
Rosate	**20**	49	**91**

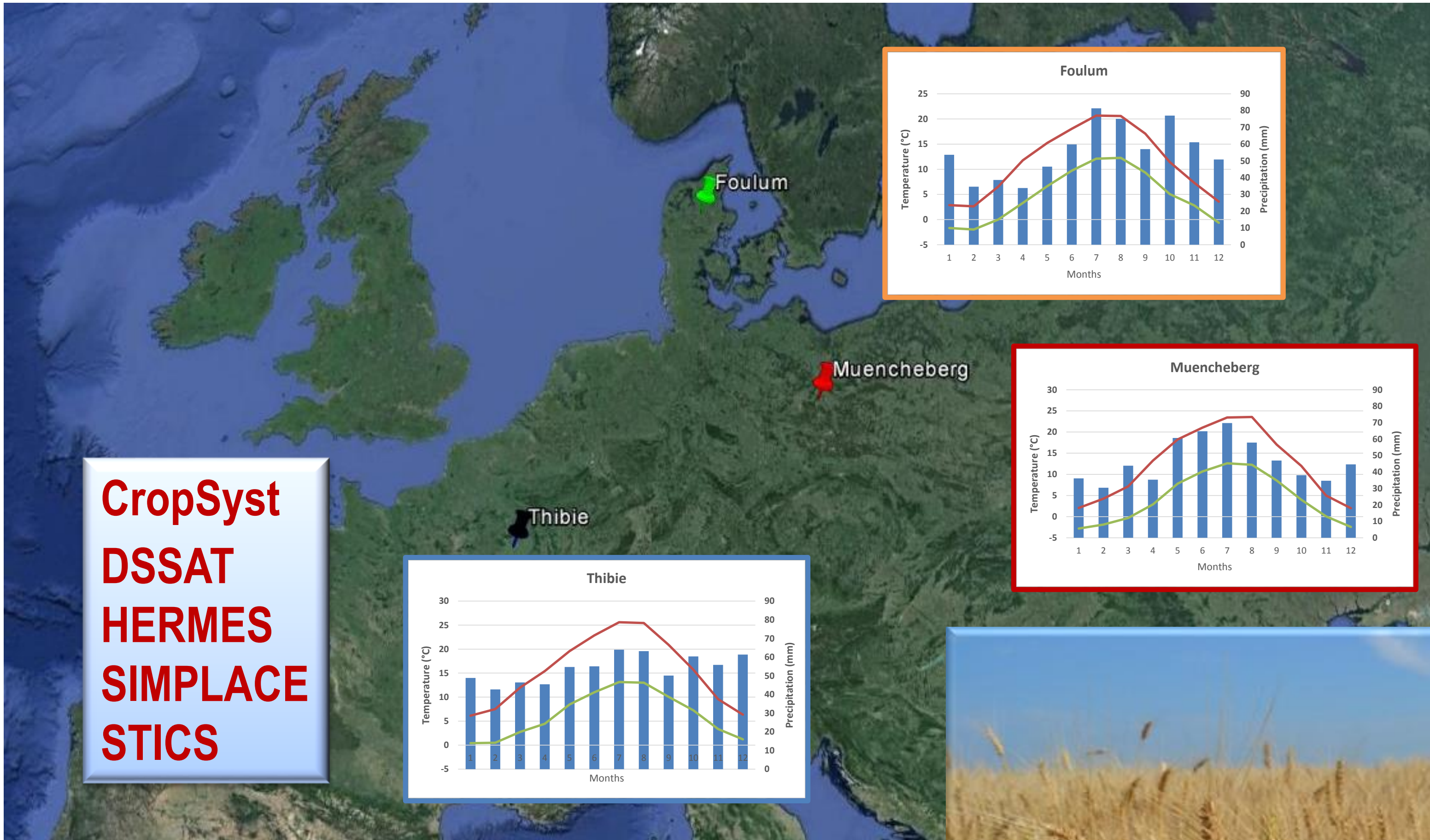
Complexity

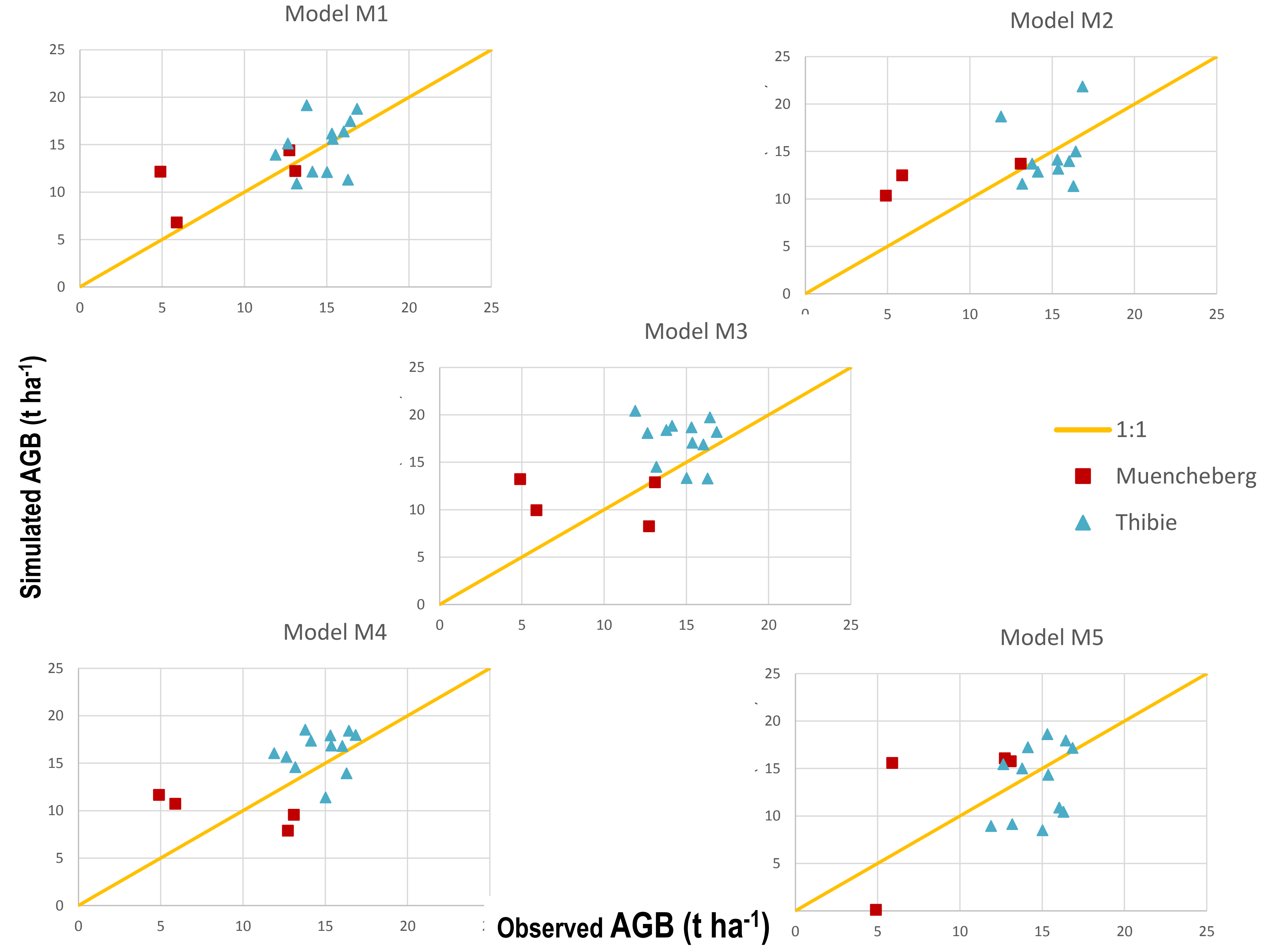
EF	M1	M2	M3
C. d'Agogna	0.90	0.95	0.93
Vercelli	0.92	0.97	0.96
Mortara	0.96	**0.98**	**0.98**
Rosate	0.92	**0.62**	**0.48**
I_R	**0. 16**	1.24	1.71

Robustness

Wheat simulations:

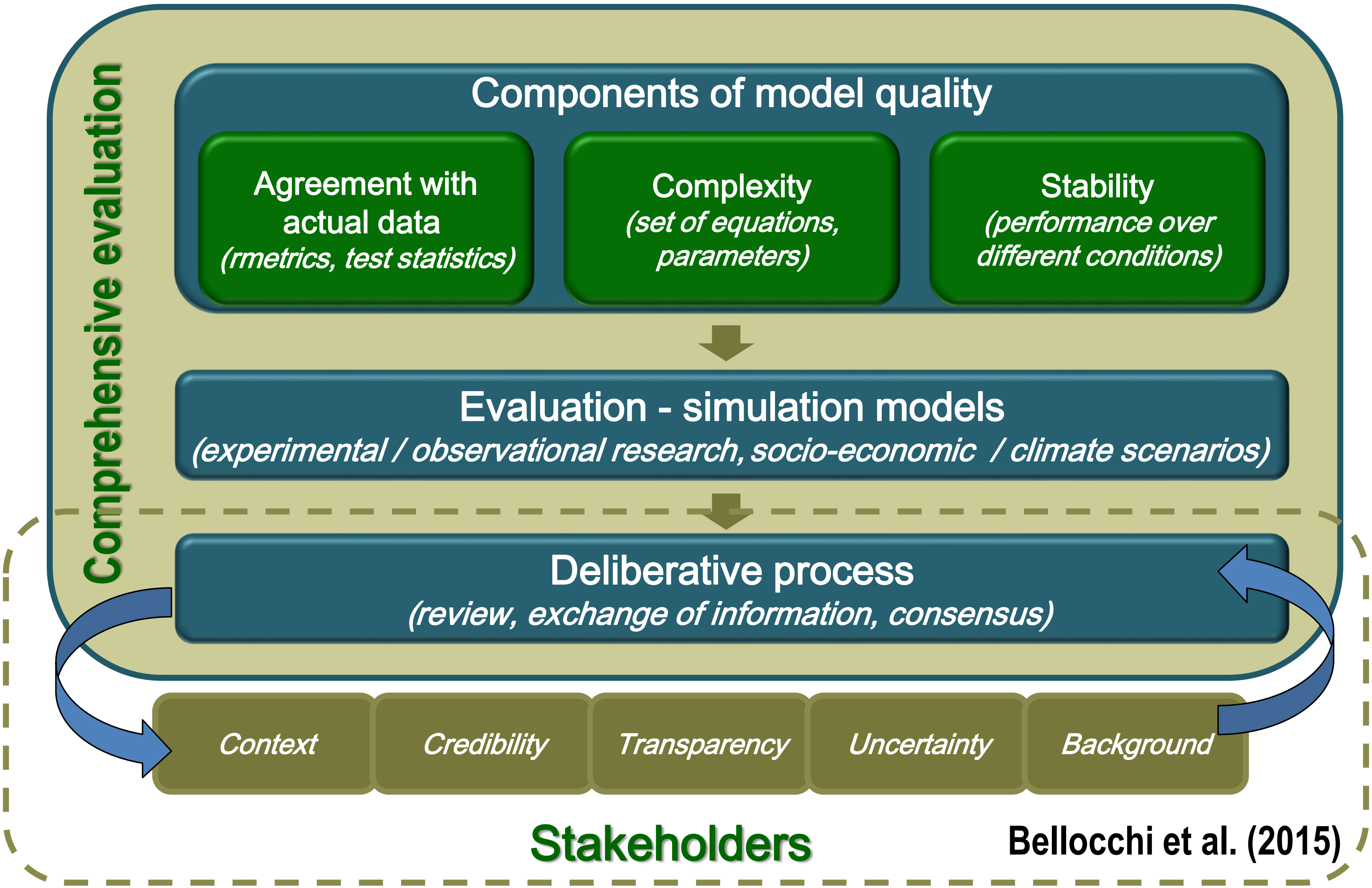
above-ground biomass at maturity




Model M1
Model M2
Model M3
Model M4
Model M5
Simulated AGB (t ha-1)
Observed AGB (t ha-1)
1:1
Muencheberg
Thibie
0
5
10
15
20
25

Model	Aboveground biomass at maturity: performance metrics, modules and indicator					
	$\overline{P(t)}$	$\bar{r}$	$\bar{d}$	$\overline{R_p}$	$\overline{w_k}$	I_R
M1	0.23	0.46	0.64	0.32	1.99E-13	65.4
M2	0.20	0.46	0.60	0.28	2.66E-11	6.0
M3	0.01	-0.25	0.70	0.53	0.12	149.5
M4	0.08	-0.36	0.25	0.50	0.88	344.6
M5	0.08	0.49	0.60	0.37	1.34E-08	377.6
	Agreement			Complexity		Robustness
M1	0.8000			0.7975		1.0000
M2	0.8000			0.7975		0.6049
M3	1.0000			1.0000		1.0000
M4	0.8640			0.5000		1.0000
M5	0.8640			0.8944		1.0000
	MQI_m					
M1	0.8976					
M2	0.7471					
M3	1.0000					
M4	0.8428					
M5	0.9640					

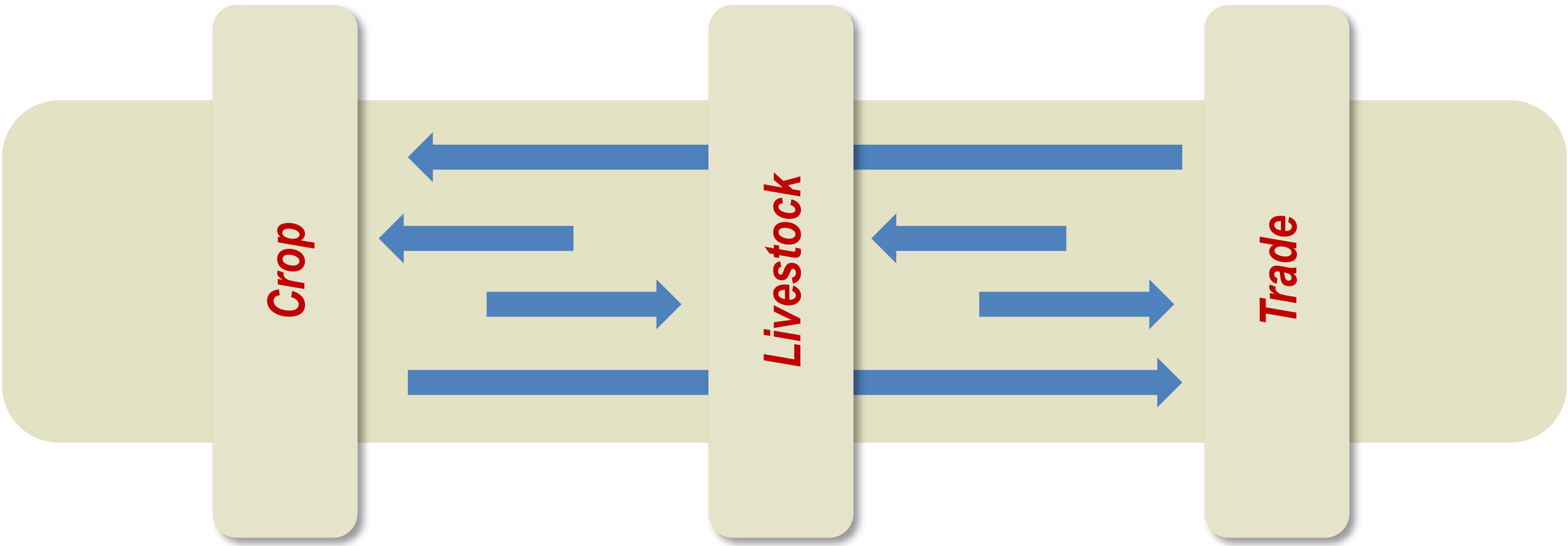
Model evaluation / deliberative process



Bellocchi et al. (2015)

Towards a consolidated, internationally-agreed protocol to evaluate models: what does go forth?

- Review of settings
  - Selection of metrics
  - Attribution of thresholds and weights
- Extension to multiple outputs



Institutionalising deliberative practices for context-specific model evaluations

Model evaluation(s) are (sometimes) an (important) orientating landmark in the skyline of decisions, without replacing them

To evaluate simulation models (in agriculture) is far more urgent as many of the (tactical and strategic) decisions (in agriculture) are based on model outcomes

Dealing with (existing) and designing (new) agricultural systems is a priority that deliberations about model evaluation contribute to accomplish in a more efficient (maybe more appropriate) manner, in any case with more awareness if (genuine) collective deliberations are possible

The central issue is to think and conceive model evaluation in a (clear) decisional perspective about type of model, operability, transparency, etc.

As several models are at hand, "mod-diversity" imposes the analysis of case-by-case issues, while also integrating the specific context in a larger-scale perspective (in space and time)

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Thank you for your attention.