RMT modélisation

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Uncertainty analysis of a crop model: approach and illustration of two case studies.

Analyse d'incertitude d'un modèle de culture : démarche et illustration sur deux cas d'étude.

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Context

- **Use of crop models**
  - to predict yield of year
  - for tactical decision
  - to evaluate management strategies
    - Example 1 : irrigation
    - Example 2 : choice of variety
  - …

- **But how accurate are the results ?**

- **A collaborative project of RMT modélisation**
  - “Associate a level of error in the predictions of mathematical models for agronomy and livestock.” (ACTA 2010-2012)
  - 10 studies cases

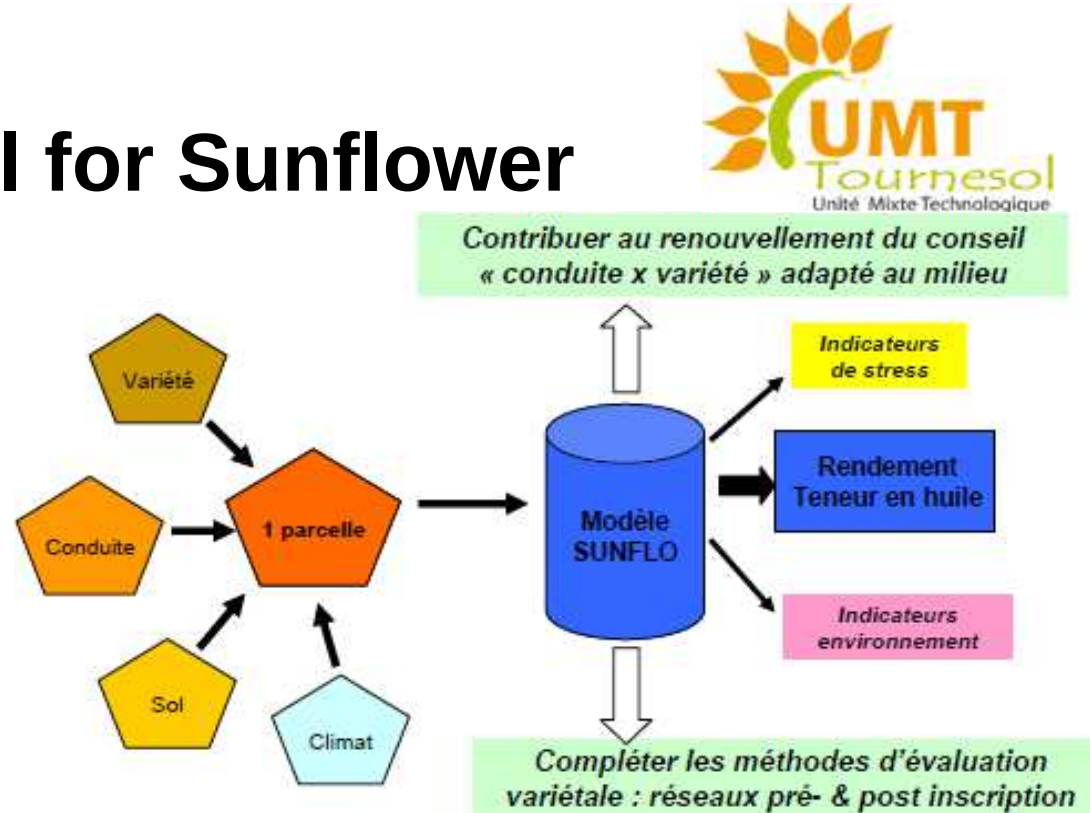
Two crop model studies cases

MODERATO. Decision crop model for maize

- evaluate irrigation strategies taking into account weather uncertainty

SUNFLO. Crop model for Sunflower

- simulate genotype-specific performance of the sunflower crop in contrasting environments



An operational approach to associate a level of uncertainty to model outputs.

- **Definition of requirements and constraints**
  1) specification of the variables of interest
  2) selection of indicators of uncertainty
  3) identification of sources of uncertainty
  4) characterization of information available
- **Uncertainty Analysis**
  5) quantification of sources of uncertainty
  6) propagation of uncertainty
  7) point estimate (mean value)
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- **Analysis of results – Verifying Hypothesis**
  9) Analysis of the contributions to uncertainty
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1) specification of the variables of interest

- ***MODERATO***

yield for weather chosen at random $C^{random\ year}$	$p_{i,t,k}^{(s)}$ **with i chosen at random from {1, …, 49}**
yield averaged over years C^{ave}	$(1/49)\sum_{i=1}^{49} p_{i,t,k}^{(s)}$
standard deviation of yield C^{sd}	$\sqrt{\frac{1}{48}\sum_{i=1}^{49}\left[\left(p_{i,t,k}^{(s)} - (1/49)\sum_{i=1}^{49} p_{i,t,k}^{(s)}\right)^2\right]}$
number of years with yield < 6t/ha C^{poor}	$\sum_{i=1}^{49} 1\left\{p_{i,t,k}^{(s)} < 6\right\}$

2) selection of indicators of uncertainty

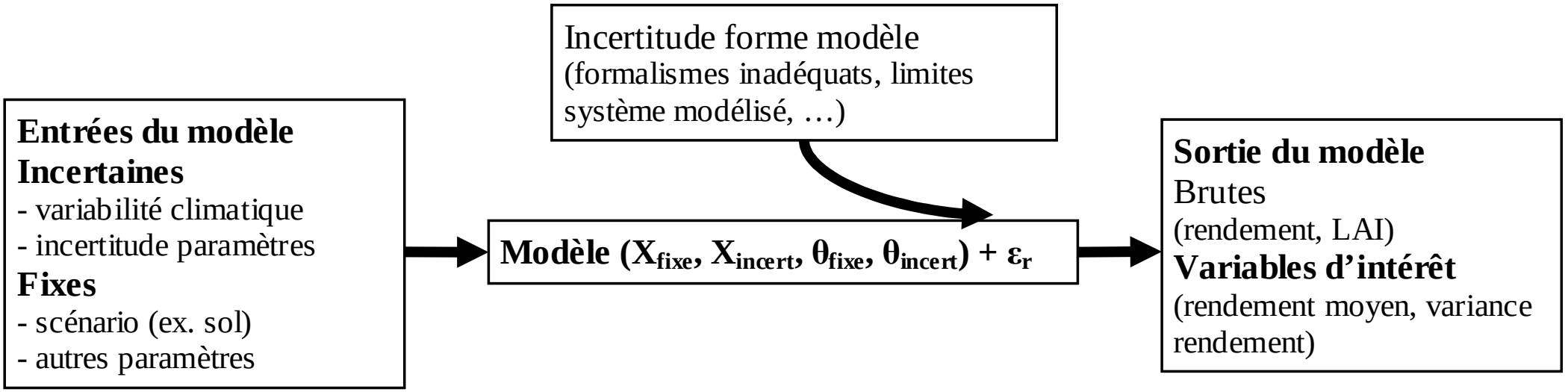
- **For each situation**
  - **Complete uncertainty distribution for variables of interest**

But, more useful

- **Confidence interval for each prediction**

3) identification of sources of uncertainty

- ***SUNFLO and MODERATO***



4) characterization of information available

- **Literature**
  - for a priori information on parameter distribution
- **Important experimental databases**
  - **context information (Soil, weather, sowing date…)**
  - **yield (and oil content for SUNFLO)**
  - **biomass and LAI at several dates**
  - **MODERATO : 81 simulations units with data**
    (place X year X irrigation management)
  - **SUNFLO : 167 simulations units with data**
    (place X year X management X genotype)

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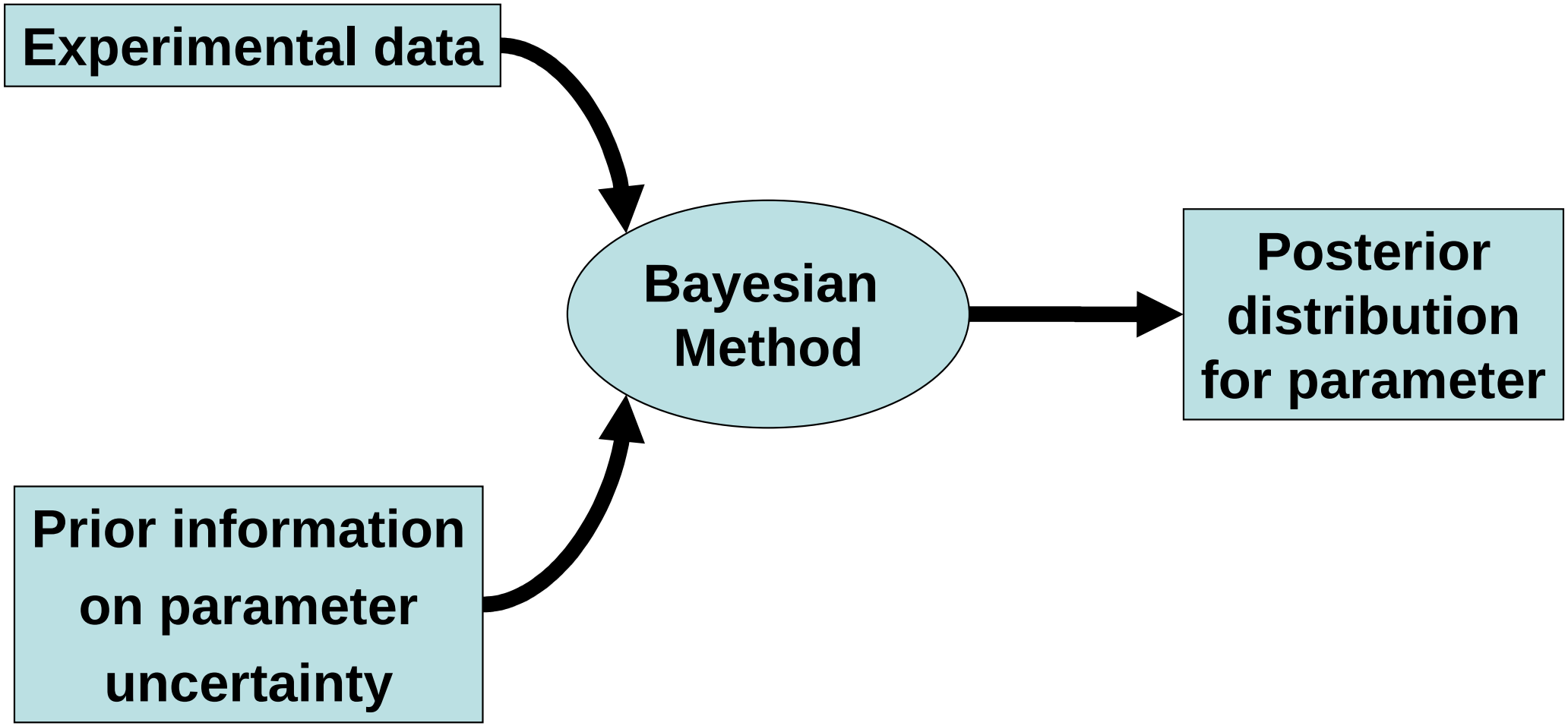
5) quantification of sources of uncertainty

- Always a costly step
- *MODERATO : Bayesian parameters calibration*

(Metropolis-Hastings within Gibbs algorithm)



MODERATO : Example for uncertainty distribution

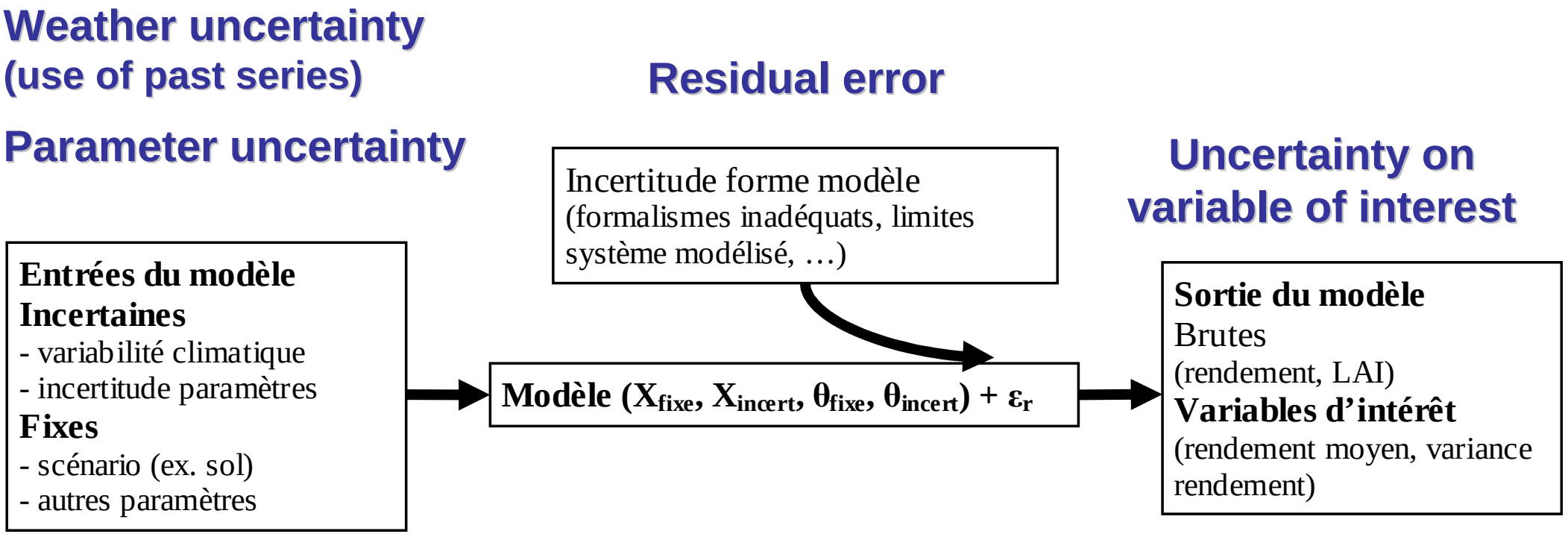
Abbrevation	units	prior distribution			posterior distribution	
		lower bound	upper bound	std dev	mean	std dev
A2sen	-	0	1	0.29	0.25	0.042
A3sen	-	1	2	0.29	1.79	0.093
himax	-	0.45	0.55	0.029	0.51	0.021
P1logi	-	0.65	0.99	0.098	0.66	0.013
P1sen	-	0.0011	0.0021	0.00028	0.0019	0.0002
P2logi	(°C days)-1	0.007	0.013	0.00087	0.0086	0.00007
P2sen	-	4.2	7.8	1.04	5.9	0.11
R1hi	-	1	2	0.29	1.8	0.13
R1rue	-	0.0001	1	0.029	0.83	0.093
R1sf	-	0.4	1.2	0.23	0.96	0.19
R2hi	-	1	2	0.29	1.1	0.068
R2rue	-	0.0001	1	0.029	0.95	0.040
R2sf	-	0.4	1.2	0.23	0.63	0.12
rue1	g/MJ	3	4	0.29	3.0	0.019
rue2	g/MJ	3	4	0.29	3.03	0.037
σ_1^2	(t/ha)²				1.3	0.11
σ_2^2	(t/ha)²				2.3	0.11
σ_3^2	-				0.81	0.032

SUNFLO: Example of uncertainty distribution

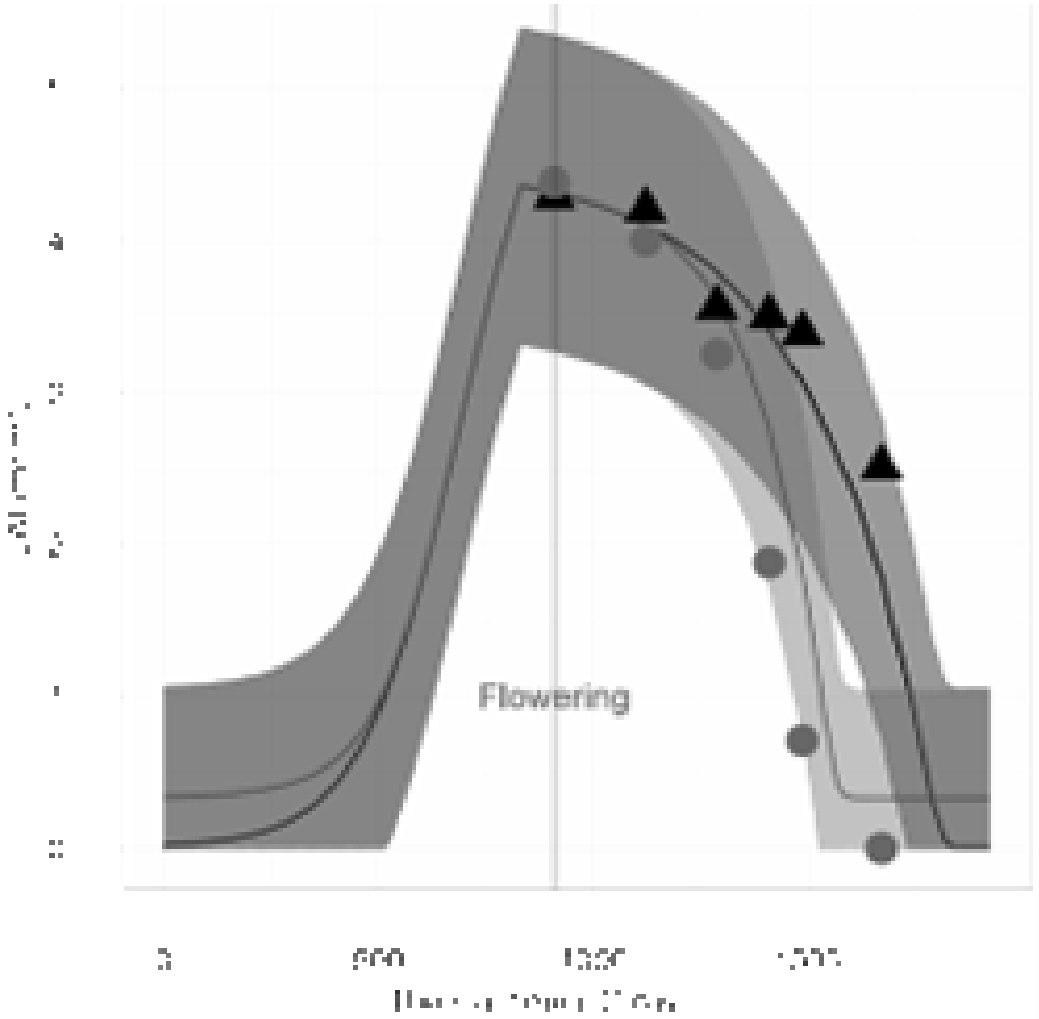
- Genotypic parameter estimated from specific greenhouse experiment

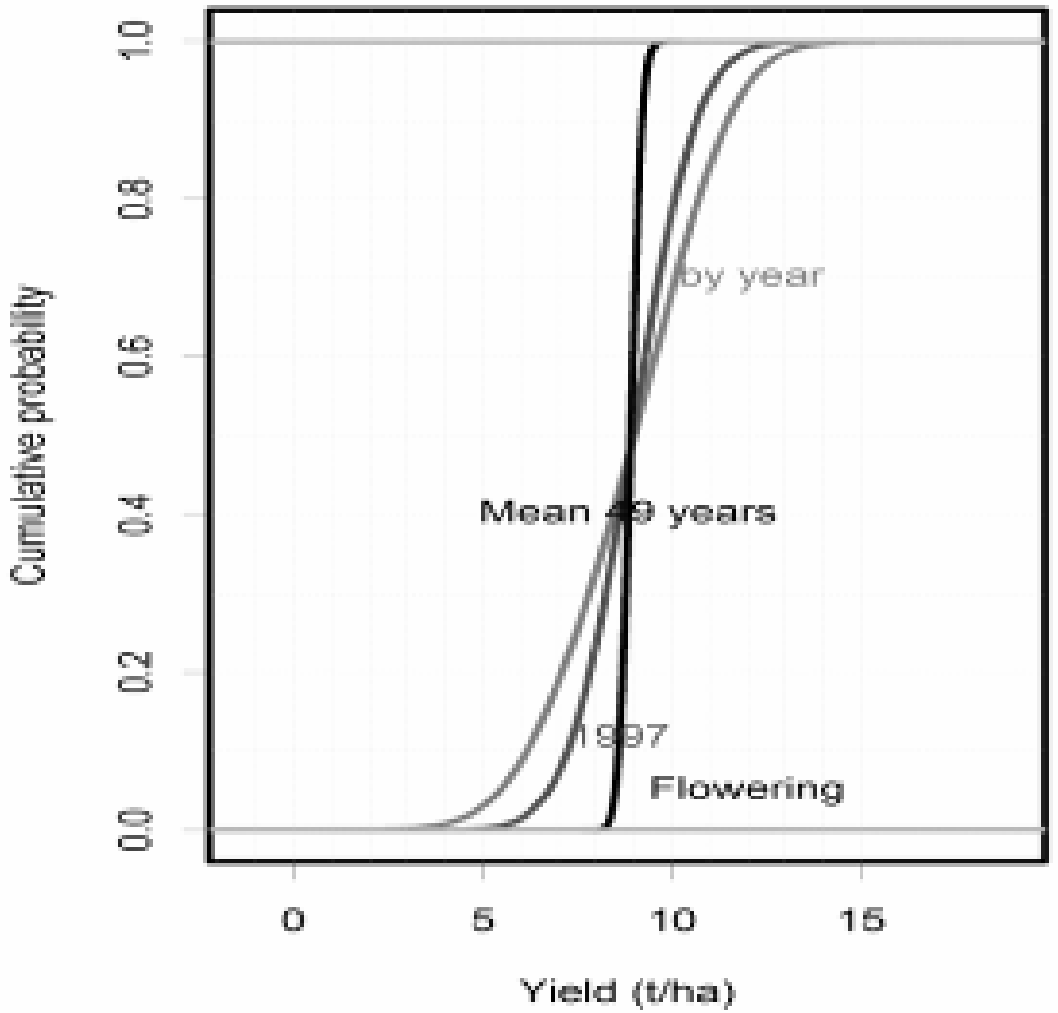
Variétés	a_LE	sd a_LE	CV a_LE	a_TR	sd a_TR	CV a_TR
Airelle	-2.7250	0.6870	0.2521	-6.8300	0.9040	0.1324
Euroflor	-15.5720	4.4810	0.2878	-6.1410	1.3100	0.2133
Frankasol	-6.7880	2.3310	0.3434	-7.2350	0.4700	0.0650
Heliasol	-5.2190	1.0260	0.1966	-5.2230	0.9250	0.1771
INRA6501	-4.5970	0.6110	0.1329	-7.2930	1.1030	0.1512
Melody	-3.8100	0.2940	0.0772	-5.6510	0.4730	0.0837
Prodisol	-4.2520	0.4770	0.1122	-7.1320	0.7090	0.0994

6) propagation of uncertainty



MODERATO : Example of output with uncertainty





7) point estimate (mean value)
8) value of the indicators of uncertainty

	strategy	mean	sd	Conf. Int. 90%
yield for weather chosen at random $C^{random\ year}$	flowering	8.9	2.0	5.5-12.1
	rain-fed	3.6	2.1	0.3-7.4
	late	7.9	2.3	4.1-11.6
	early	7.6	2.8	2.9-11.9
yield averaged over years C^{ave}	flowering	8.9	0.2	8.5- 9.3
	rain-fed	3.6	0.3	3.1- 4.0
	late	7.9	0.3	7.5-8.3
	early	7.6	0.2	7.2-8.0
standard deviation of yield C^{sd}	flowering	2.0	0.2	1.7-2.4
	rain-fed	2.1	0.2	1.8-2.4
	late	2.3	0.2	2.0 -2.7
	early	2.8	0.2	2.5-3.1
number of years (out 49) with yield < 6t/ha C^{poor}	flowering	4.2	1.8	1-7
	rain-fed	42.7	1.9	39-46
	late	10.9	2.5	7 -15
	early	14.8	2.4	11-19

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9) analysis of the contributions to uncertainty

- **Sensitivity analysis…**

10) verification with data

- ***MODERATO : testing confidence intervals using experimental data***

response variable	percent of cases in 50% credible interval	percent of cases in 90% credible interval
Yield	53	91
LAI	51	89
biomass	65	95

11) specification and analysis of assumptions

- **Model of error…**

Conclusion

- **Generic approach, important to promote for model used for agronomy and livestock**

- **Estimating uncertainty sources is time consuming**

- **Uncertainty results depends on chosen variable of interest**
  - **Less uncertainty to predict average yield among years than for individual prediction**

  => Important to well define variable of interest