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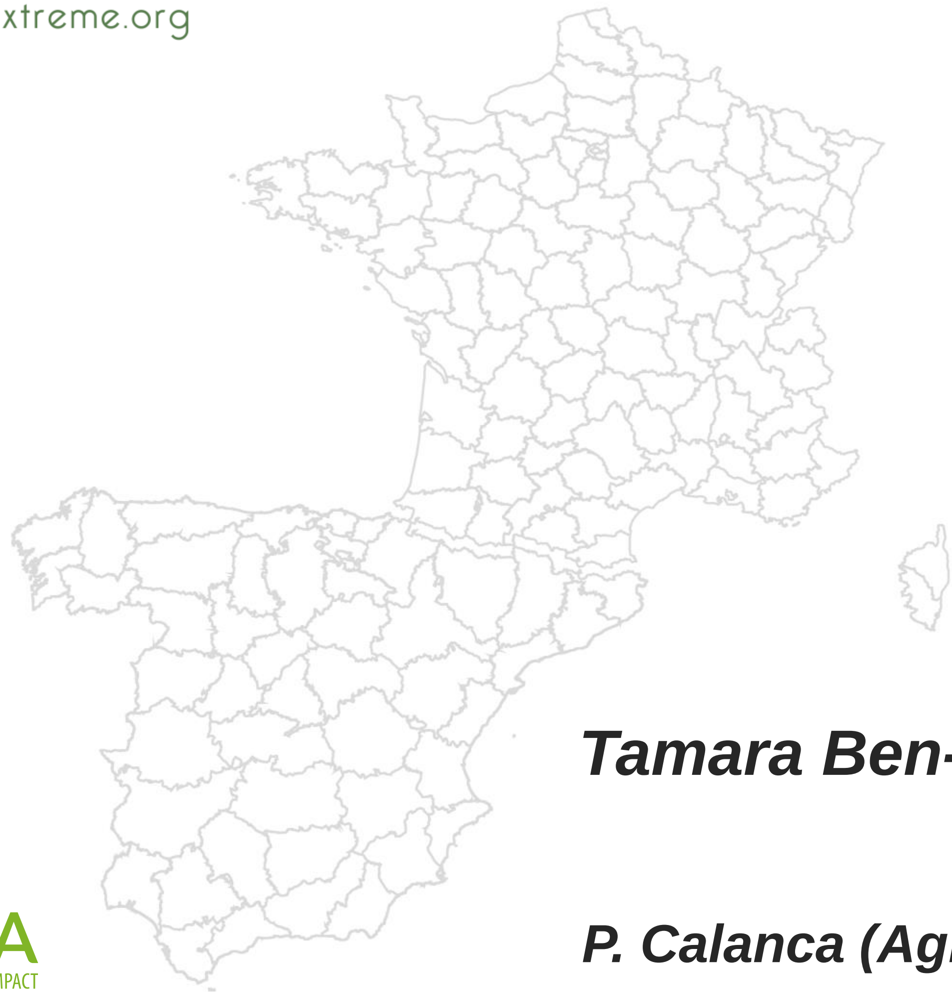
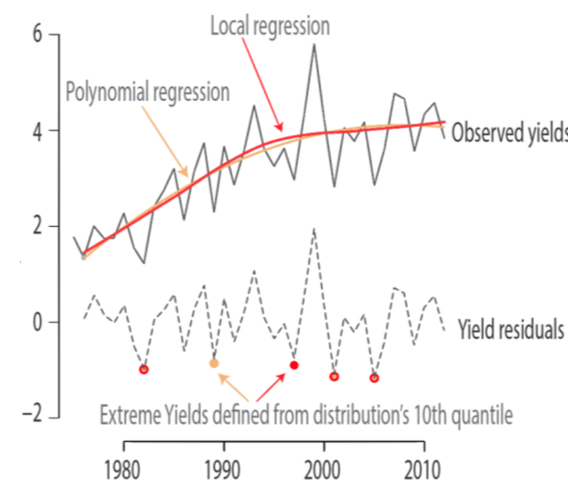
Identifying accurate climate indicators of extreme wheat and maize yield loss





Tamara Ben-Ari & David Makowski (INRA)

P. Calanca (Agroscope), M. Van der Velde (JRC)

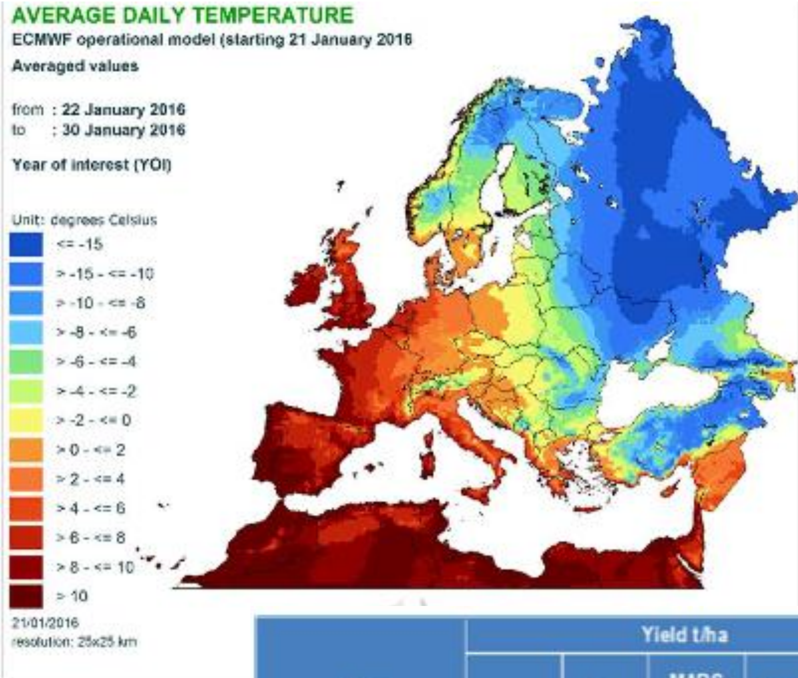
DG_AGRI Meeting, September, 20th 20

INRA
SCIENCE & IMPACT

WHAT ARE THE **SKILLS** OF **EXISTING TOOLS** ?

(FOR EXTREME YIELD LOSSES ANTICIPATION)

Context



Crop	Yield t/ha				
	Avg 5yrs	May Bulletin	MARS 2016 forecasts	% Diff 16/5yrs	% Diff May
TOTAL CEREALS	5.27	5.54	**5.53**	+4.9	-0.2
Total Wheat	5.60	5.85	**5.82**	+3.9	-0.5
soft wheat	5.83	6.11	**6.07**	+4.1	-0.7
durum wheat	3.33	3.45	**3.48**	+4.4	+0.9
Total Barley	4.72	4.99	**5.01**	+6.3	+0.4
spring barley	4.12	4.24	**4.33**	+4.9	+2.1
winter barley	5.57	5.98	**5.94**	+6.5	-0.7
Grain maize	6.93	7.31	**7.35**	+6.1	+0.5
Rye	3.76	3.85	**3.77**	+0.3	-2.1
Triticale	4.20	4.26	**4.20**	-0.2	-1.4
Rape and turnip rape	3.20	3.29	**3.24**	+1.0	-1.5
Potato	32.07	33.21	**33.16**	+3.4	-0.2
Sugar beet	71.80	73.39	**73.20**	+2.0	-0.3
Sunflower	1.94	2.01	**2.08**	+7.1	+3.5

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Online version
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European Commission

JRC MARS Bulletin
Crop monitoring in Europe
June 2016

Fairly good yield outlook for the EU-28
Excellent conditions in Spain; less positive in western Europe

Content:
1. Agro-meteorological overview
2. Observed canopy conditions by remote sensing
3. Country analysis
4. Crop yield forecasts
5. Pasture – regional monitoring
6. Atlas

Covers the period from 1 May until 15 June

Climate data

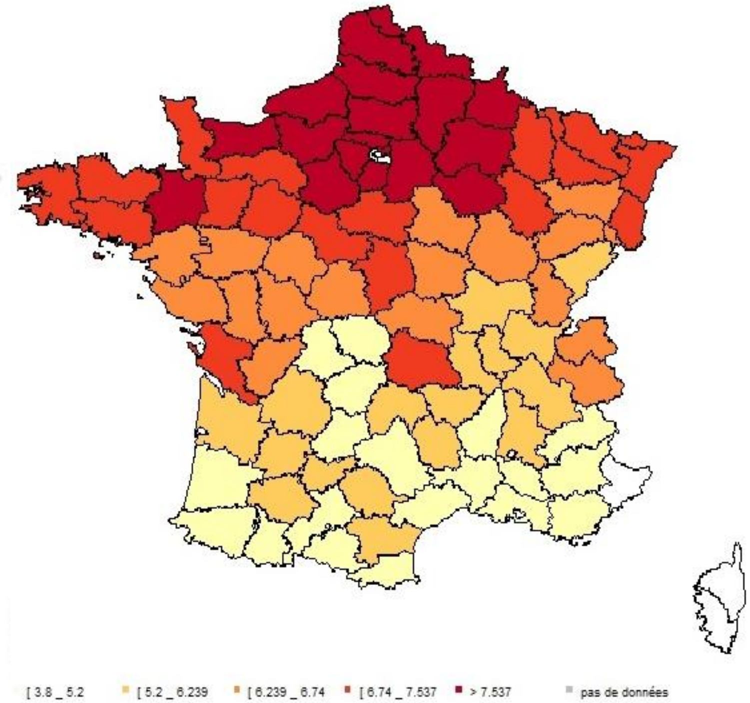
- T_{max} and T_{min}(°C)
- Angot radiation (MJ/m^2)
- Rainfall (mm)
- Vapor pressure deficit (hPa)
- Potential evapotranspiration (mm/day)
- Drought indices:

$$\mathrm{ARID} = 1 - \frac{\mathrm{T_a}}{\mathrm{T_p}}$$

$$\mathrm{FU} = -\frac{\mathrm{P}}{\mathrm{ET_0}} + [1 + (\frac{\mathrm{P}}{\mathrm{ET_0}})^{\mathrm{w}}]^{(1/\mathrm{w})}$$

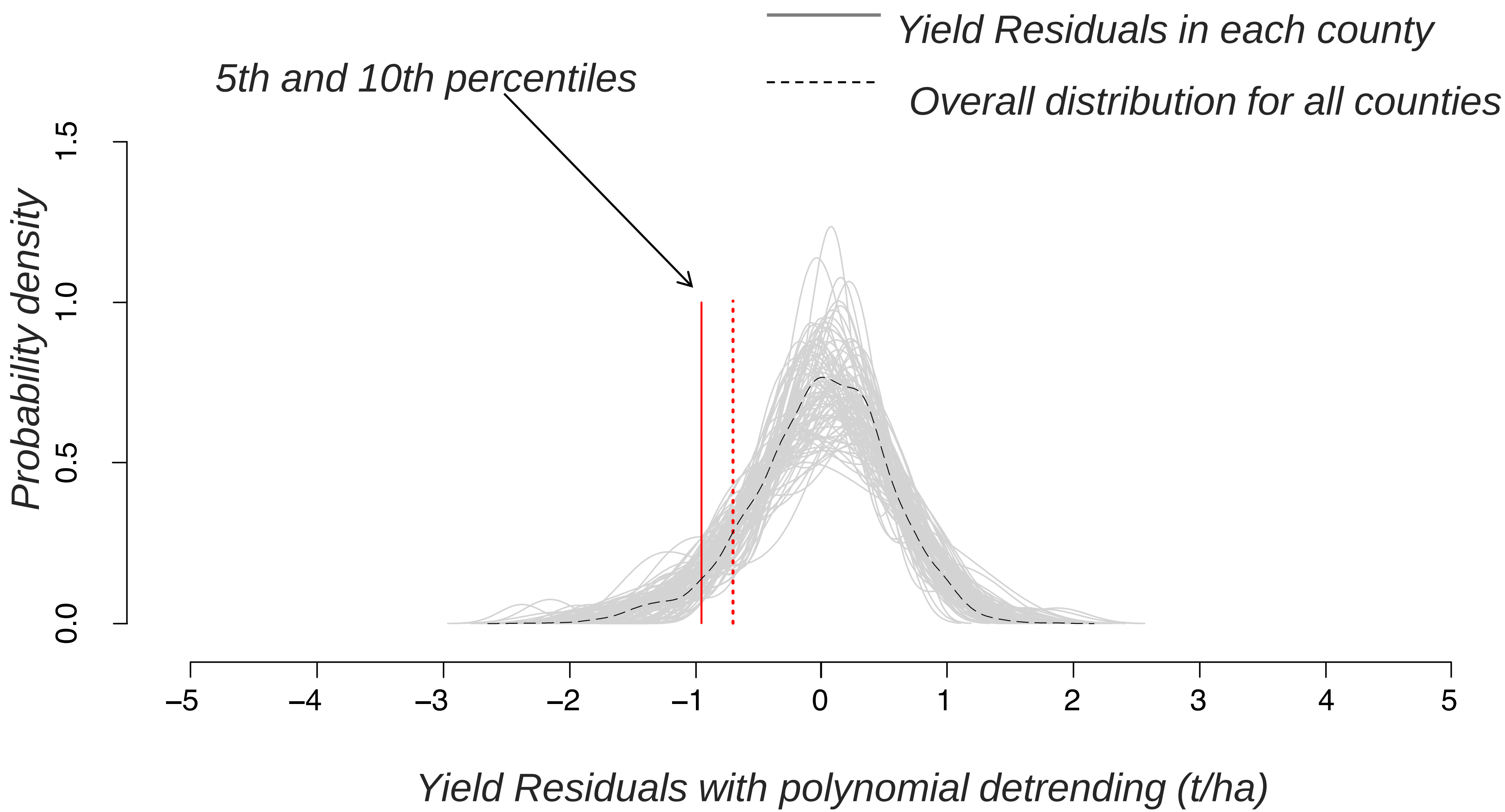
- Critical temperatures (heat and frost) and critical ARID
- The North Atlantic Oscillation (NAO)
- Potential and water-limited simulated yields (WOFOST model, JRC)

Yield Data



- Yield time series (1976/1989 – 2013)
- NUTS3 scale

YIELD RESIDUALS (WHEAT IN FRANCE)



RECEIVING OPERATOR CHARACTERISTIC (ROC) ANALYSIS

- ROC is based on the evaluation of a **classification rule**

"Maize yield loss is extreme (i.e., lower than 5th or 10th percentile) if maximum temperature (I) exceeds a critical threshold (I_T)"

- Two types of errors :

	Optimal Classification	
Classification rule	Non-Extreme Yield loss	Extreme Yield loss
$I<I_T$	TRUE NEGATIVE	FALSE NEGATIVE
$I>I_T$	FALSE POSITIVE	TRUE POSITIVE

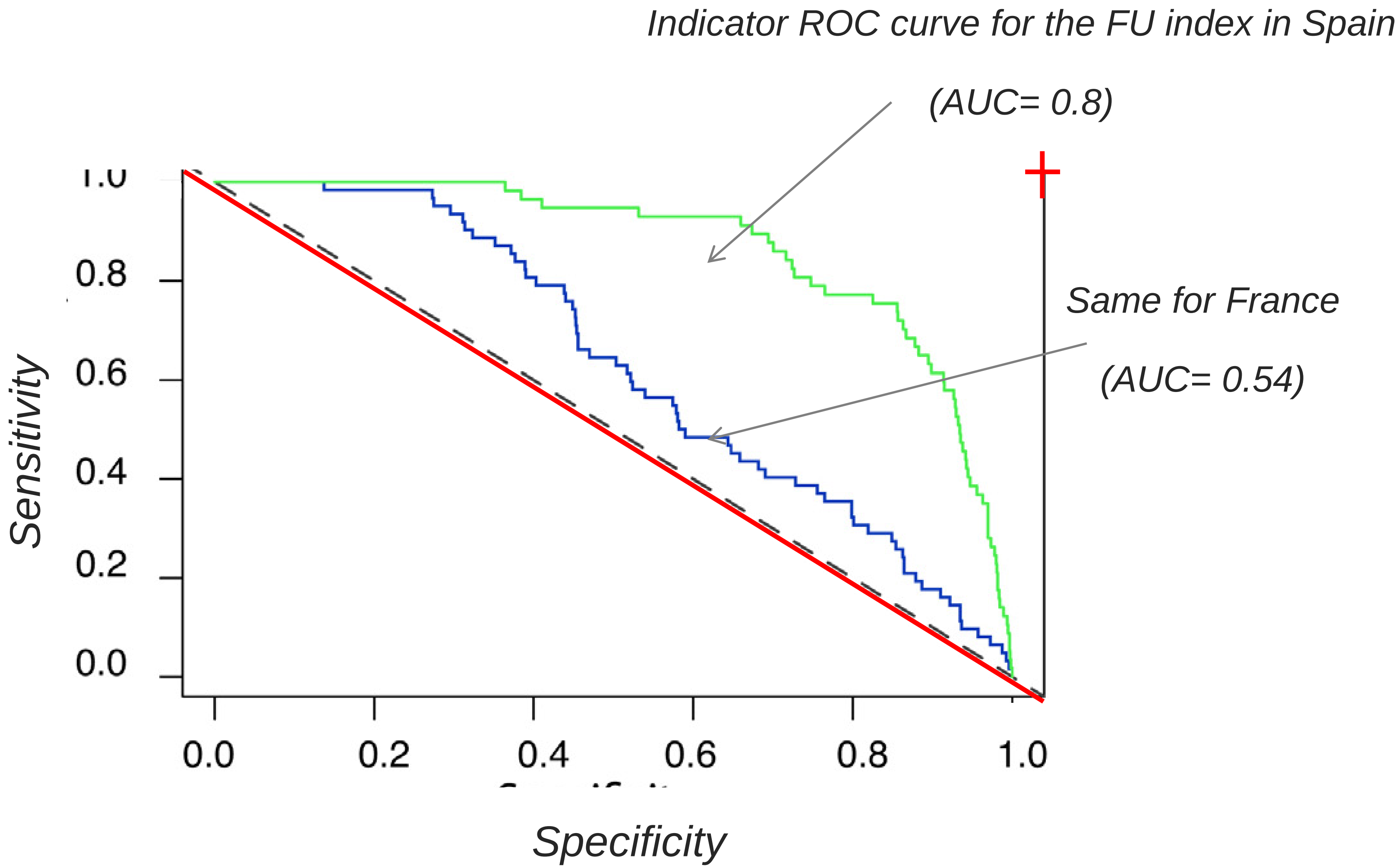
Evaluation of the classification rule

- **Sensitivity** = 1 – False negative rate = TRUE POSITIVE RATE
- **Specificity** = 1 – False positive rate = TRUE NEGATIVE RATE

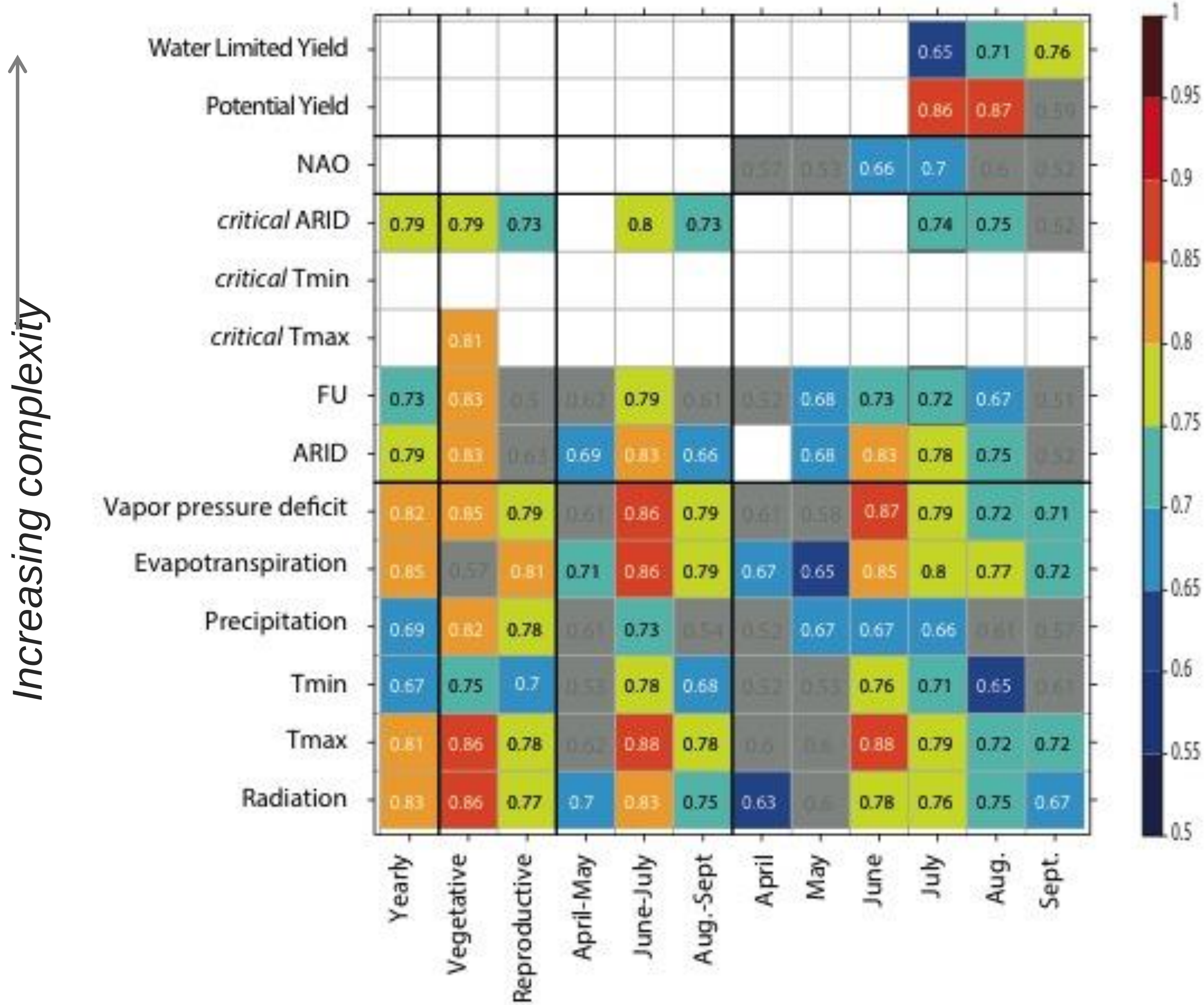
- False negative rate and false positive rate are estimated **for all possible threshold** (I_T) values (*e.g.*, the whole range of Tmax in the sample)

- The results are summarized graphically

AREA UNDER THE ROC CURVE (AUC)



COMPARING AUC SCORES FOR ALL INDICATORS /MAIZE IN FRANCE

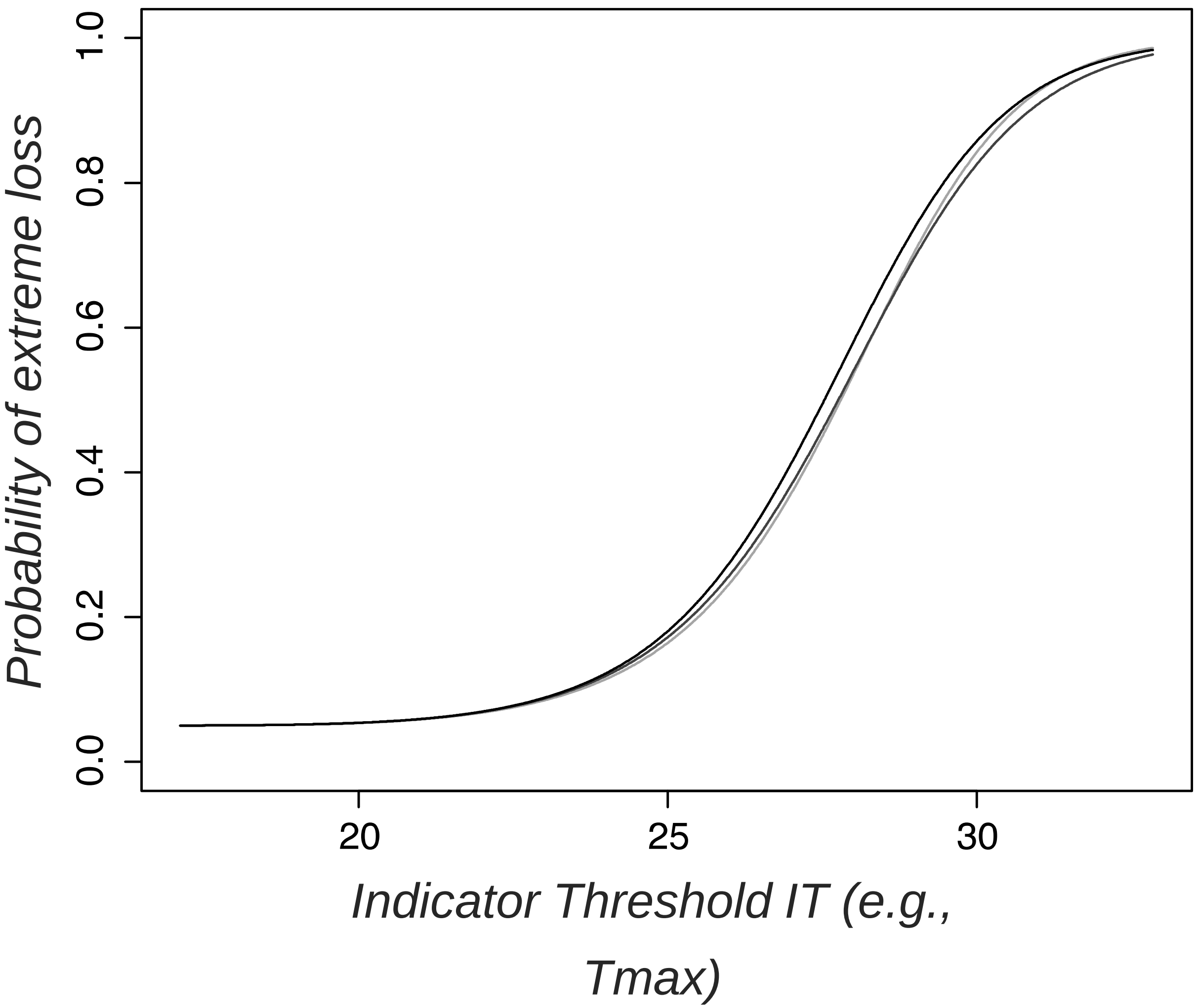


Indicators with best AUC scores in France and Spain

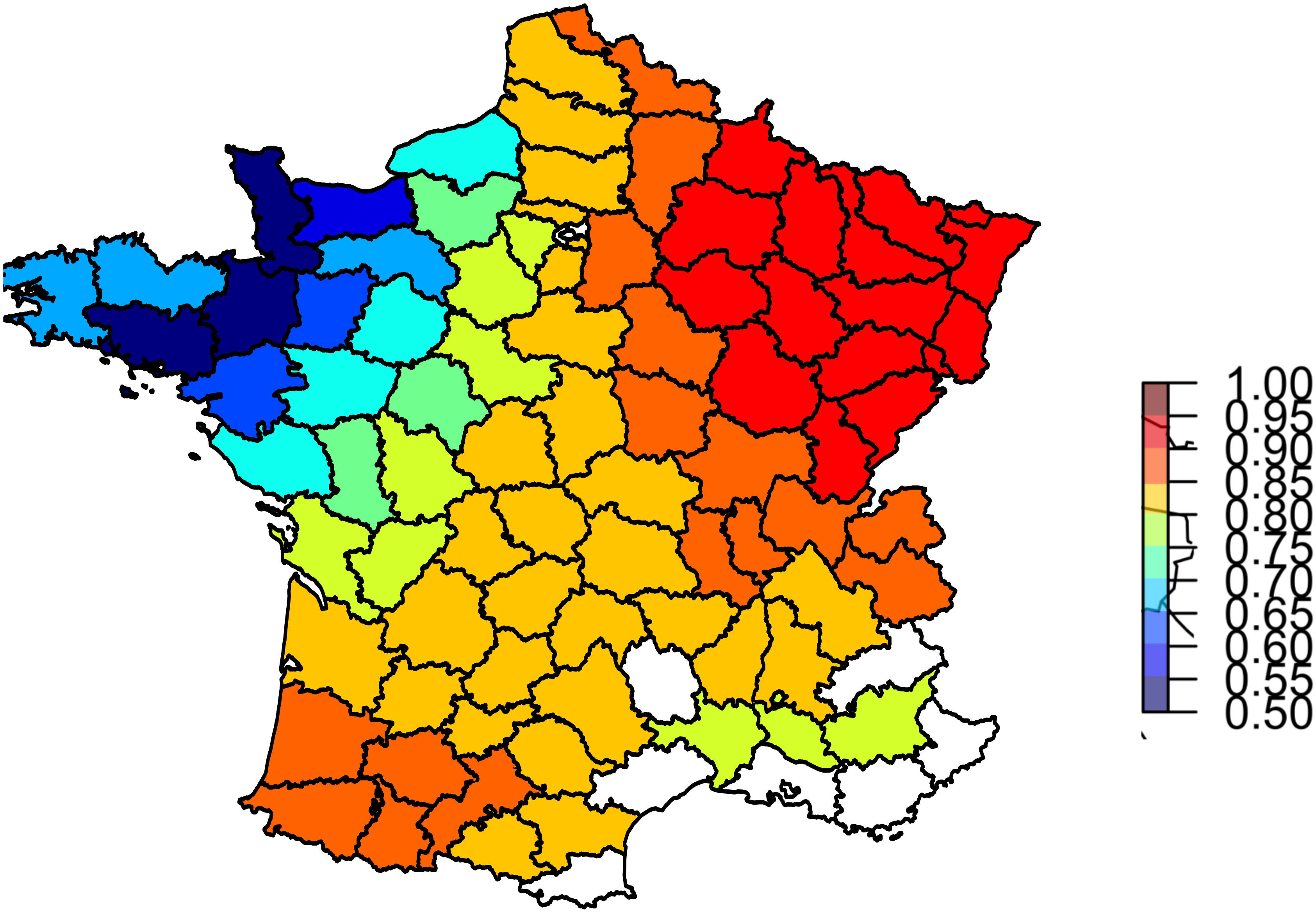
Crop	Country	Raw yield residuals
Wheat	France	**November precipitation** (0.64) July Potential yield (0.64) April Tmax (0.63) November FU indicator (0.63)
Maize	France	**June-July Tmax (0.87)** June-July VPD (0.86) Yearly critical Tmax (0.85) Vegetative critical Tmax (0.85) Vegetative VPD (0.85) Vegetative Tmax (0.85) August potential yield (0.85)
Wheat	Spain	Vegetative critical ARID (0.76) Vegetative ARID (0.76) **April critical ARID** (0.76) April ARID (0.76)
Maize	Spain	**April-May ARID** (0.64) July Tmax (0.64) August Tmax (0.64)

SENSITIVITY AND SPECIFICITIES ARE USED TO COMPUTE

PROBABILITIES OF EXTREME YIELD LOSS



Spatialization of AUC scores (Maize, June Tmax)



Summary

1. We show that "simple" climate variables are efficient in most cases

- In France for non-irrigated maize and in Spain for wheat
- They often outperform complex indicators
- Drought index is a good compromise in these countries (both crops)

3. This framework could extend as a relatively cheap solution to support decision making

4. Developments

- Combining indicators to improve accuracy
- Retrieve climatic and bioclimatic data for 2016 to compute the probability of wheat yield loss in France from combined covariates

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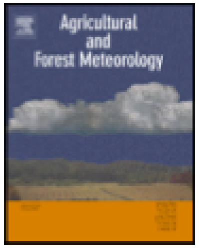

Identifying indicators for extreme wheat and maize yield losses

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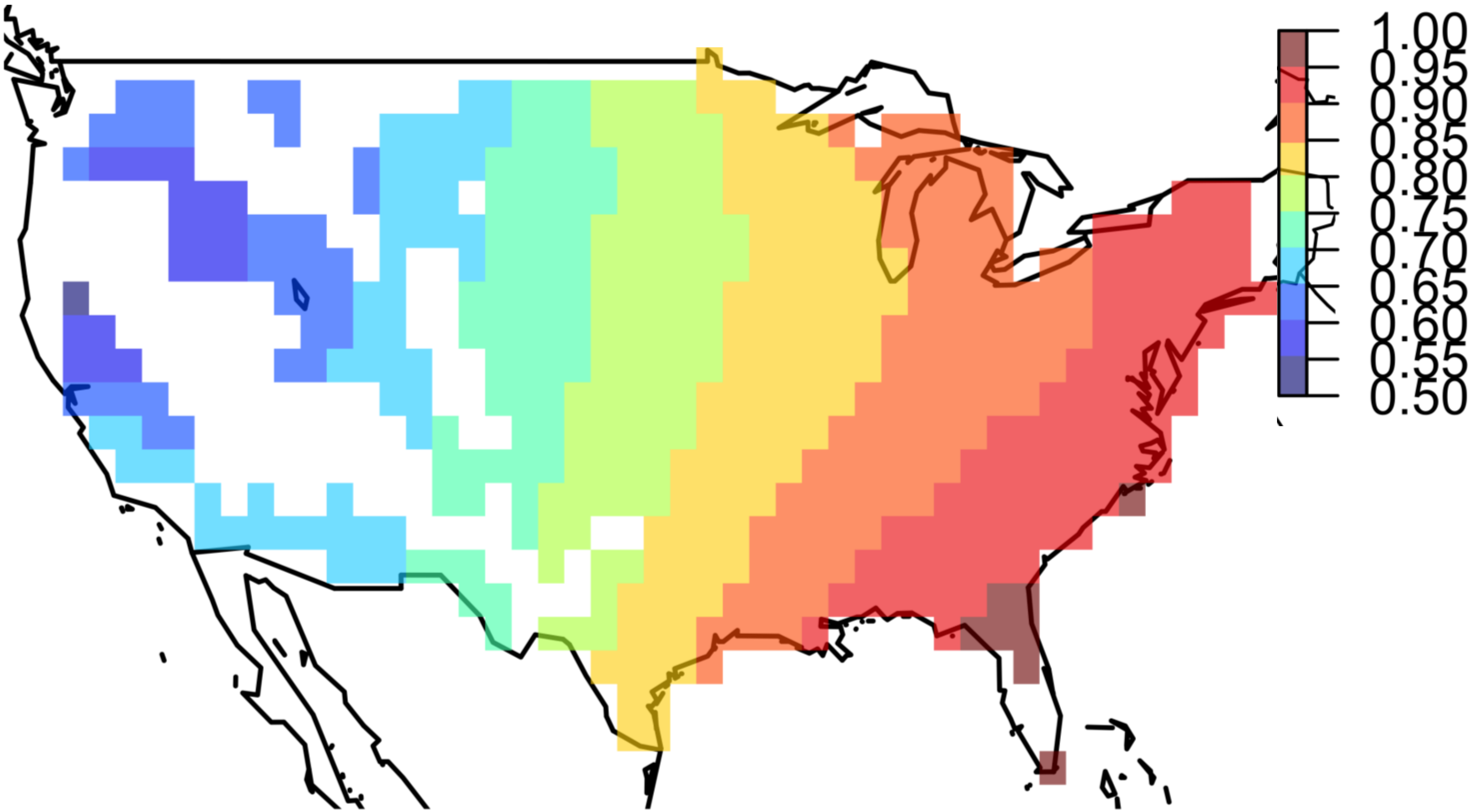
THANK YOU FOR YOUR ATTENTION

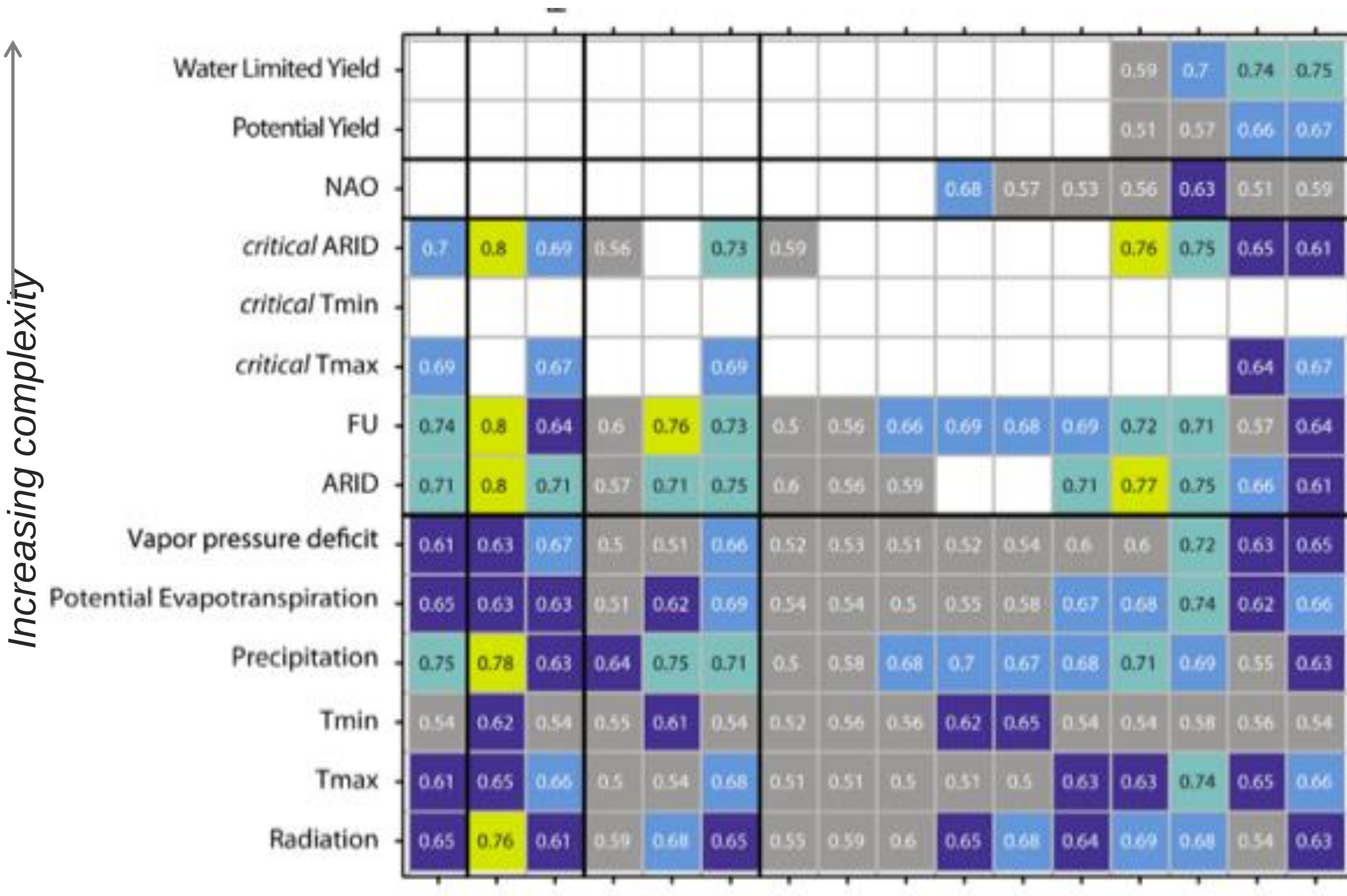
Combination of climate indicators to improve accuracy

- Indicators can be combined
- AUC scores can be spatialized to identify most relevant areas across countries
- Collaboration with NIAES (Tsukuba, Japan) with global estimated yield dataset
- Target major worldwide production basins

Performance of classification based on cumulated rainfall and solar radiation U.S

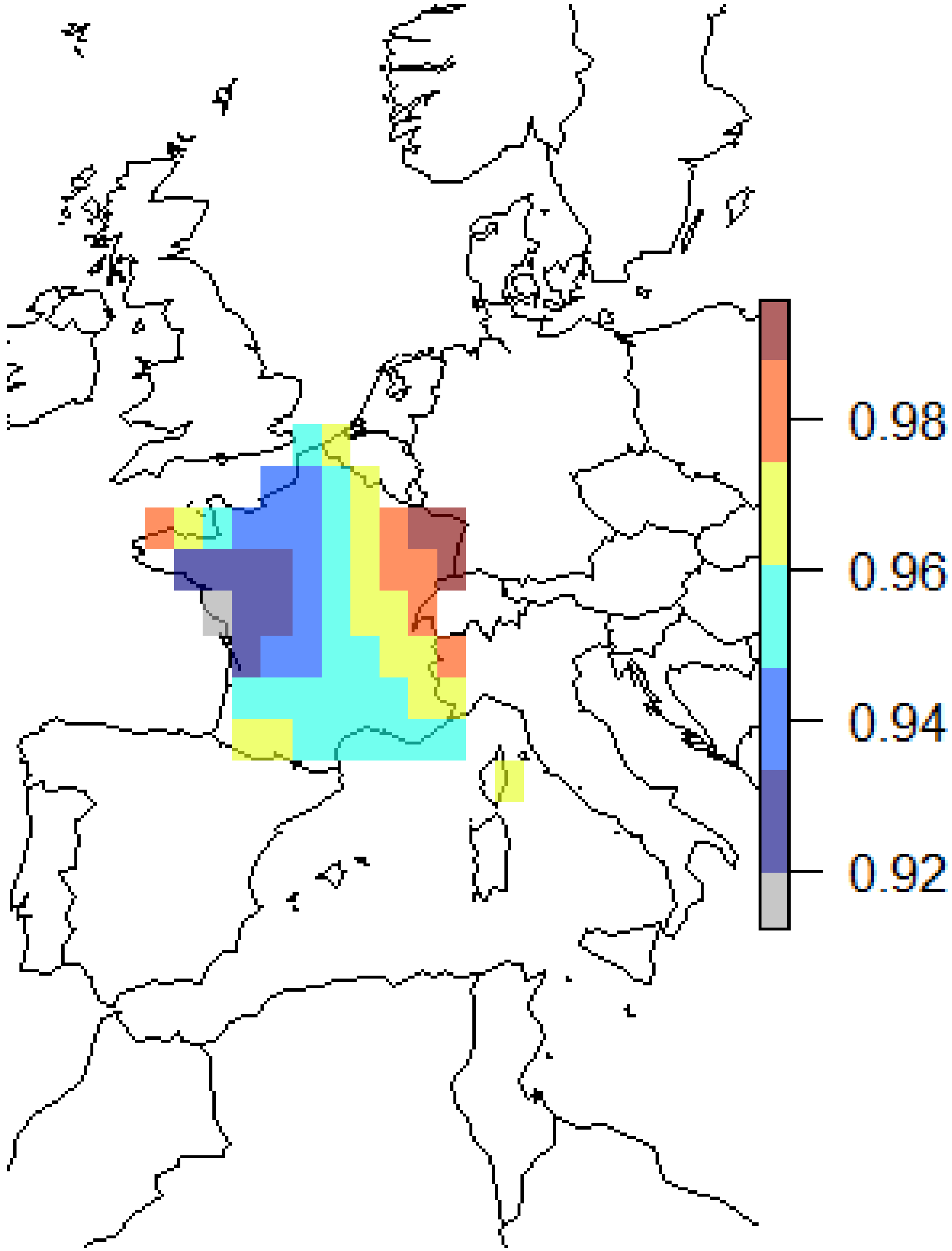


COMPARING AUC SCORES FOR ALL INDICATORS /WHEAT IN SPAIN



Wheat in Spain _ Linear detrending _ Percentile=0.05

COMBINING INDICATORS



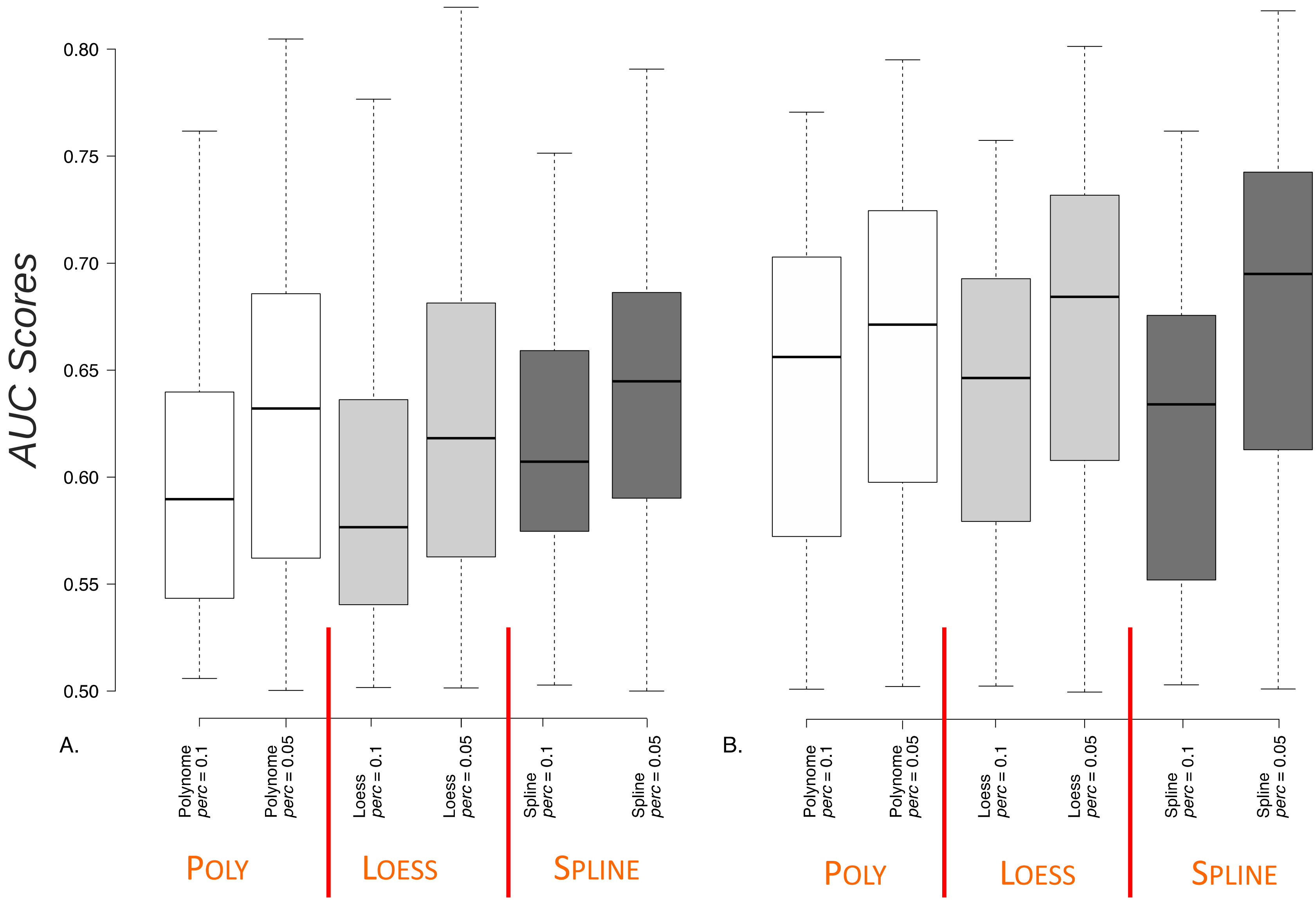
HIGH AUC
NARROW RANGE

SUPPLEMENT

- All four AUC matrices
- Bioclimatic indicators, formulas and parameters

COMPARING AUC SCORES – SENSITIVITY ANALYSIS

Effect of percentile > Effect detrending method



Posterior probability - Graphs

$$P(Ex\ Yield\ loss\ /\ I > I_T)$$

The posterior probability of extreme yield loss conditionally to I >It

POSTERIOR PROBABILITY - GRAPHS

$$P(Ex\,Yield\ loss\ /\ I > I_T) = \frac{Sensitivity\ (I_T)\ .\ P(Ex\,Yield\ loss)}{Sensitivity(I_T).\ P(Ex\,Yield\ loss) + \left(1 - specificity(I_T)\right).(1 - P(Ex\,Yield\ loss))}$$

Sensitivity (proportion of true positives) estimated from the sample

$$P\left(I > It/Ex\,Yield\ loss\right)$$

Specificity (proportion of true negatives) estimated from the sample

$$P\left(I < It/Non\ Ex\,Yield\ loss\right)$$

Posterior probability - Graphs

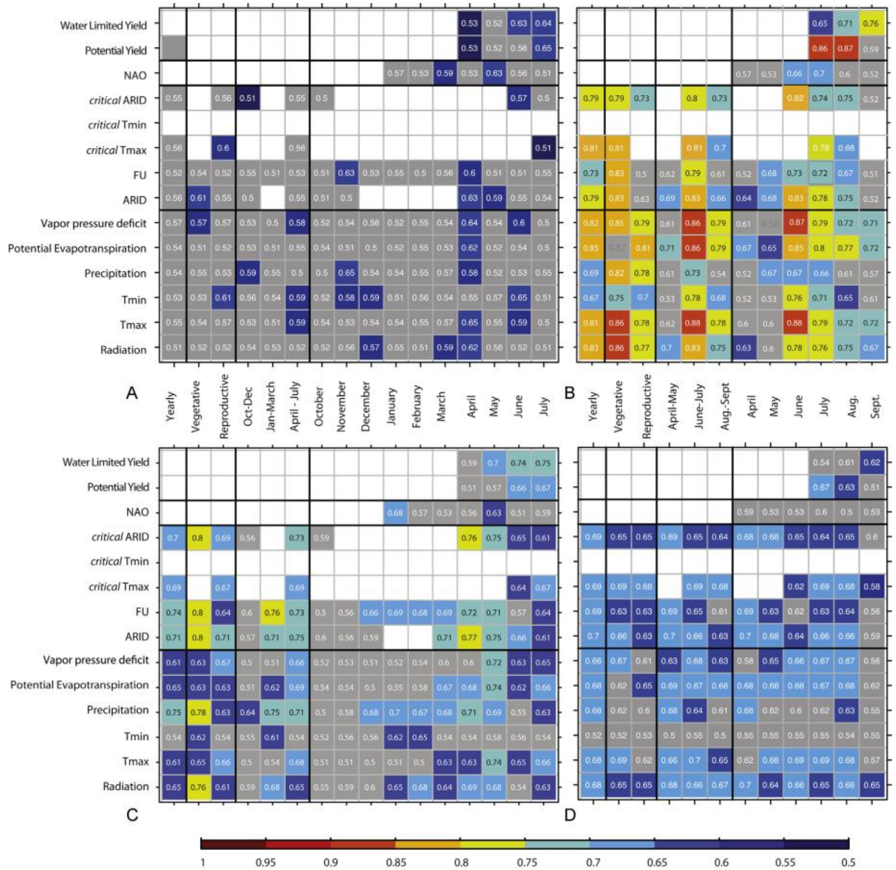
$$P(Ex\ Yield\ loss\ /\ I > I_T) = \frac{Sensitivity\ (I_T)\ .\ P(Ex\ Yield\ loss)}{Sensitivity(I_T).\ P(Ex\ Yield\ loss) + \left(1 - specificity(I_T)\right).(1 - P(Ex\ Yield\ loss))}$$

The prior probability of extreme yield loss (i.e., before measuring the indicator value).
Here it is the value of the quantile i.e., there is a 10% chance to witness an extreme yield loss (among all data points)

The prior probability of non extreme yield loss (i.e., before measuring the indicator value).
There is a 90% chance to witness a gain or moderate loss

COMPARING AUC SCORES – LIMITS (1/X)

- One score per indicator, per time period, per percentile, per detrending method and per country



whereby a simple phenological model for the accumulation of thermal units (TU) is used to distinguish between vegetative and reproductive stages. Here, TU is evaluated as:

$$\mathrm{TU} = \begin{cases} 0 & \text{if } T < T_{\mathrm{base}} \\ T - T_{\mathrm{base}} & \text{if } T_{\mathrm{base}} \leq T \leq T_{\mathrm{cutoff}} \\ T_{\mathrm{cutoff}} & \text{if } T > T_{\mathrm{cutoff}} \end{cases} \tag{4}$$

where T, T_{cutoff} and T_{base} are the daily mean, cutoff and base temperatures, respectively. Typical values for T_{base} and T_{cutoff} are 0/6 and 25/30 °C for winter wheat/maize. TU requirements to reach emergence (start of the vegetative stages) and anthesis (start of the reproductive stages) are taken from Soltani and Sinclair (2012). Finally, we also consider the North Atlantic Oscillation index as an additional index combining information on atmospheric pressure (Hurrell, 1995).

$$\mathrm{ARID} = 1 - \frac{T_a}{T_p},$$

Table 1
Parameter values for defining critical temperatures (no unit) and critical ARID (no unit).

Indicator	Definition	Critical value	References
Heat	$T_{max} > T_{max.cr}$	34 (wheat)	Asseng et al. (2015)
		35 (maize)	Teixeira et al. (2013)
Frost	$T_{min} < T_{min.cr}$	−17.2 (wheat)	Porter and Gawith (1999)
		−15 (maize)	Snyder and Melo-Abreu (2005)
Drought	ARID > ARID.cr	0.85 (wheat)	Trnka et al. (2014)
		0.8 (maize)	Lobell et al. (2013)

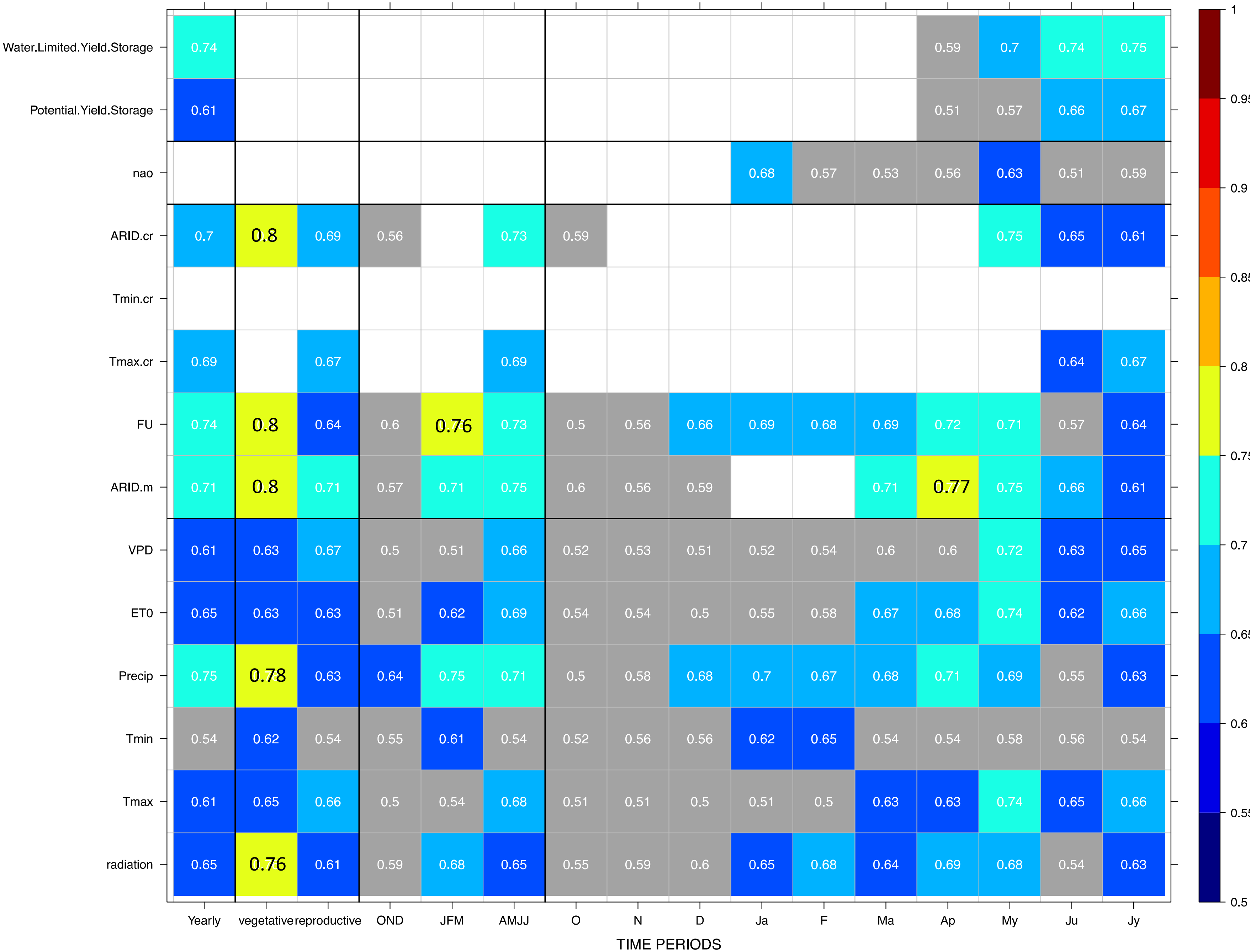
$$\mathrm{FU} = -\frac{P}{ET_0} + \left[1 + \left(\frac{P}{ET_0}\right)^w\right]^{(1/w)} \tag{3}$$

where P and ET_0 are the sums of precipitation and reference evapotranspiration over the chosen time period, and w is a shape parameter ($w = 3$).

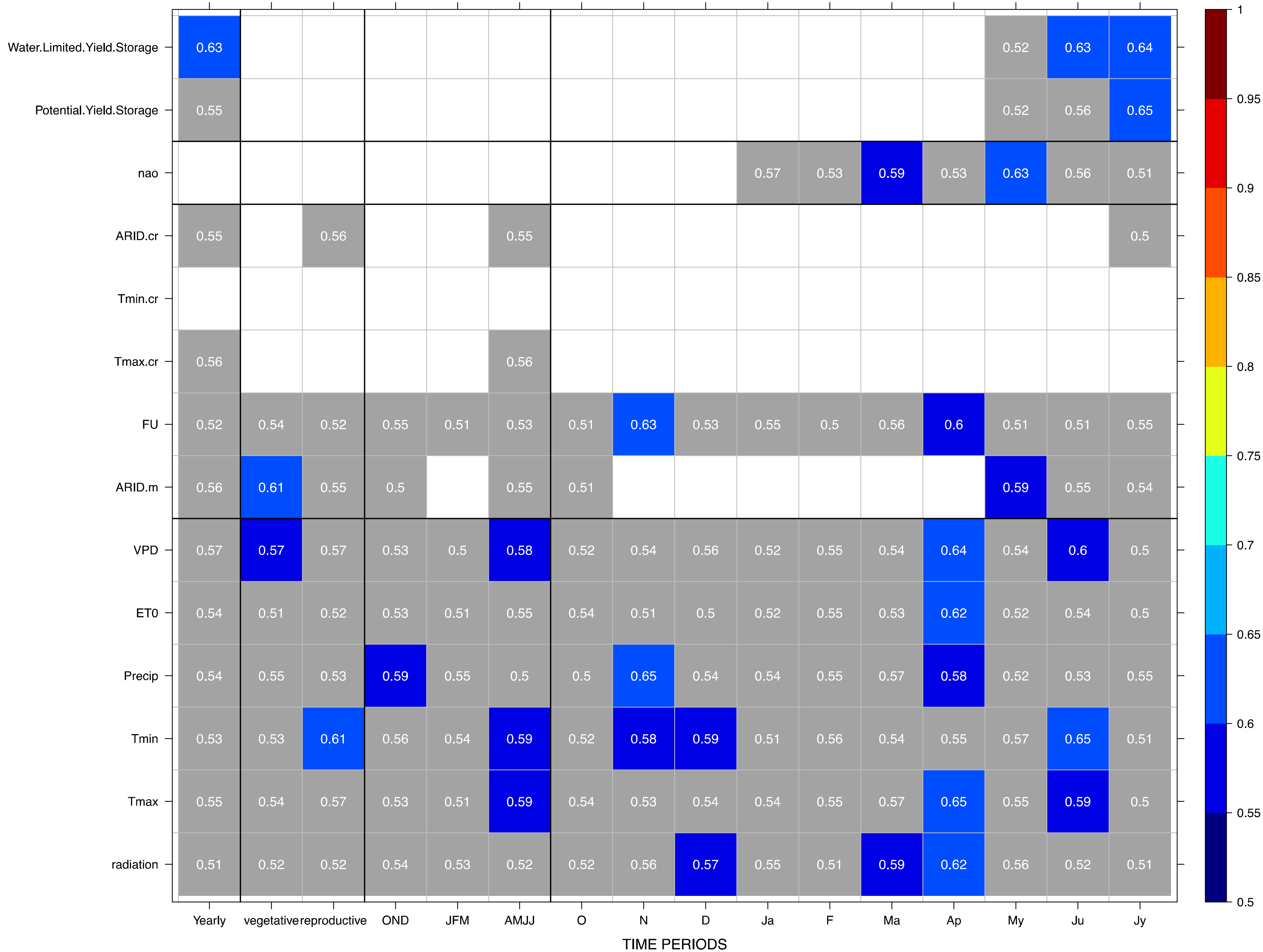
Severe yield loss thresholds

Raw residuals ($t\,ha^{-1}$)		France		Spain	
		Wheat	Maize	Wheat	Maize
Polynomial	5th percentile	−0.95	$\boxed{-2.45}$	−1.12	−1.42
	10th percentile	−0.7	−1.58	−0.81	−1.02
Local (loess)	5th percentile	−0.92	−1.74	−1.07	−1.28
	10th percentile	−0.69	−1.18	−0.77	−0.91
Cubic splines	5th percentile	−0.94	−1.80	$\boxed{-0.86}$	$\boxed{-0.86}$
	10th percentile	−0.68	−1.10	$\boxed{-0.51}$	$\boxed{-0.60}$

Table 1. Values in t/ha below which a given yield is considered extreme



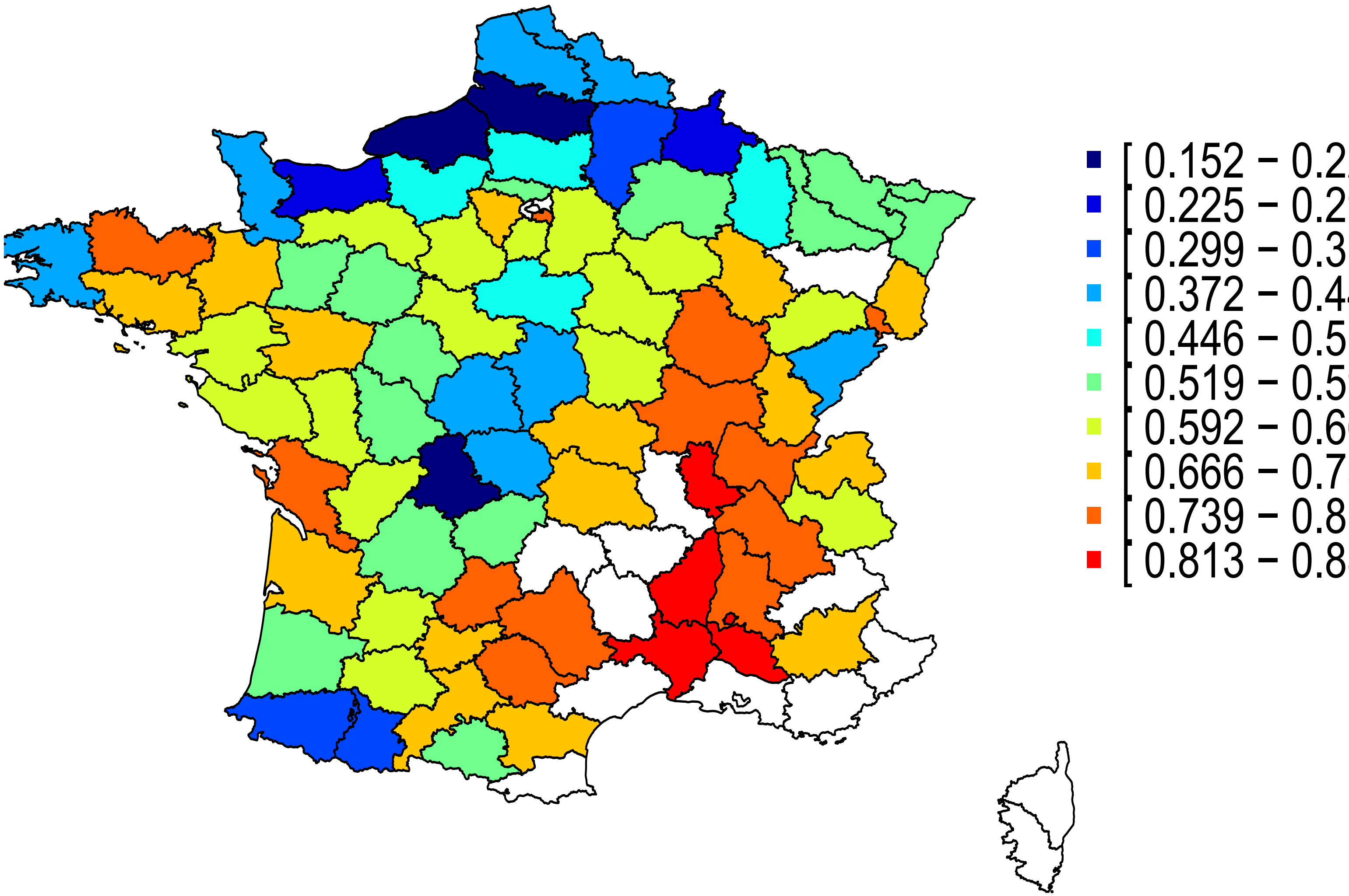
Wheat in Spain _ Linear detrending _ Percentile=0.05



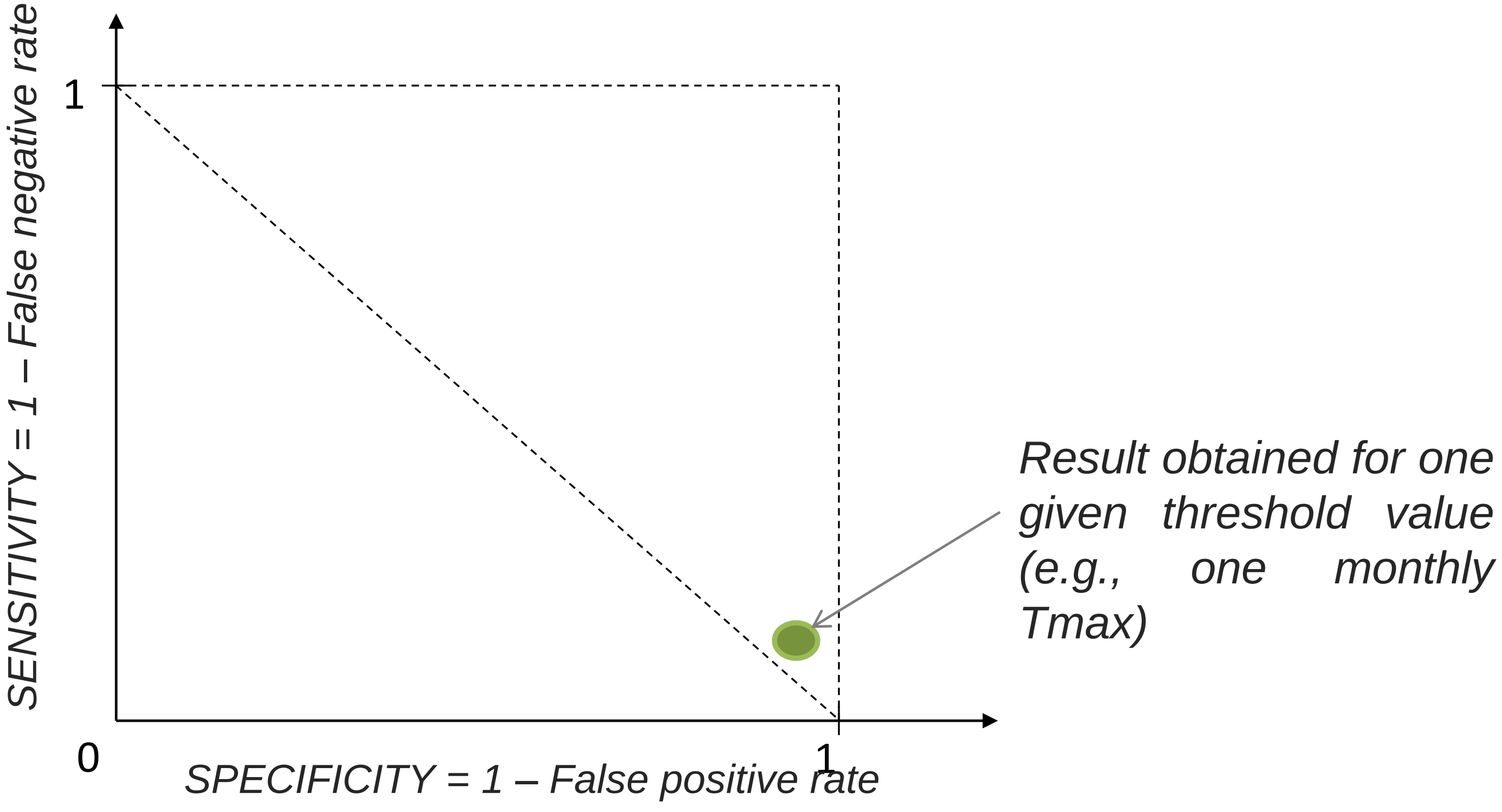
Wheat in France_ Linear detrending _ Percentile=0.05

CLIMATE DATA

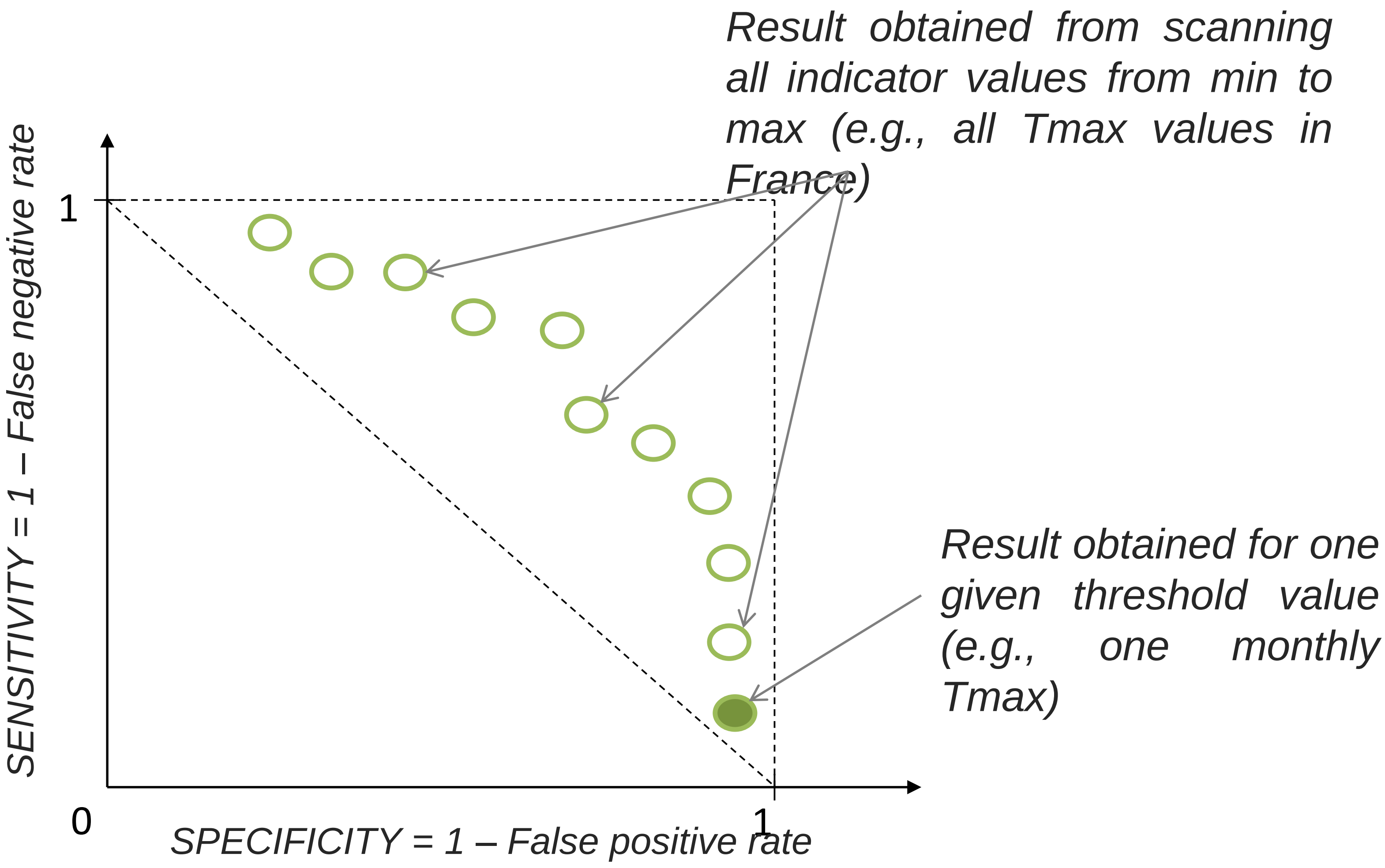
EXAMPLE: ARID [0-1] IN 2003



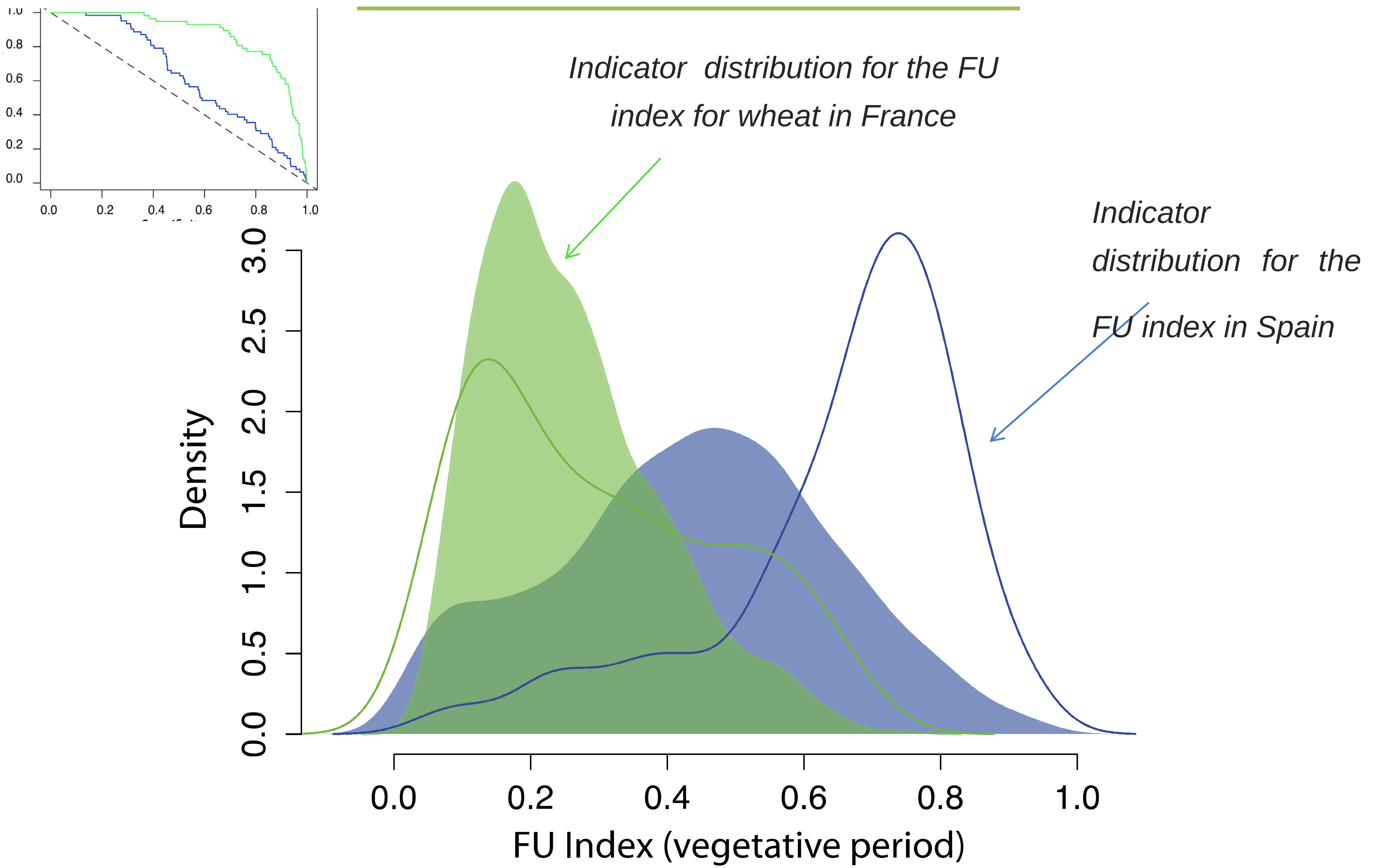
EVALUATION OF ALL CLASSIFICATION RULES



EVALUATION OF ALL CLASSIFICATION RULES



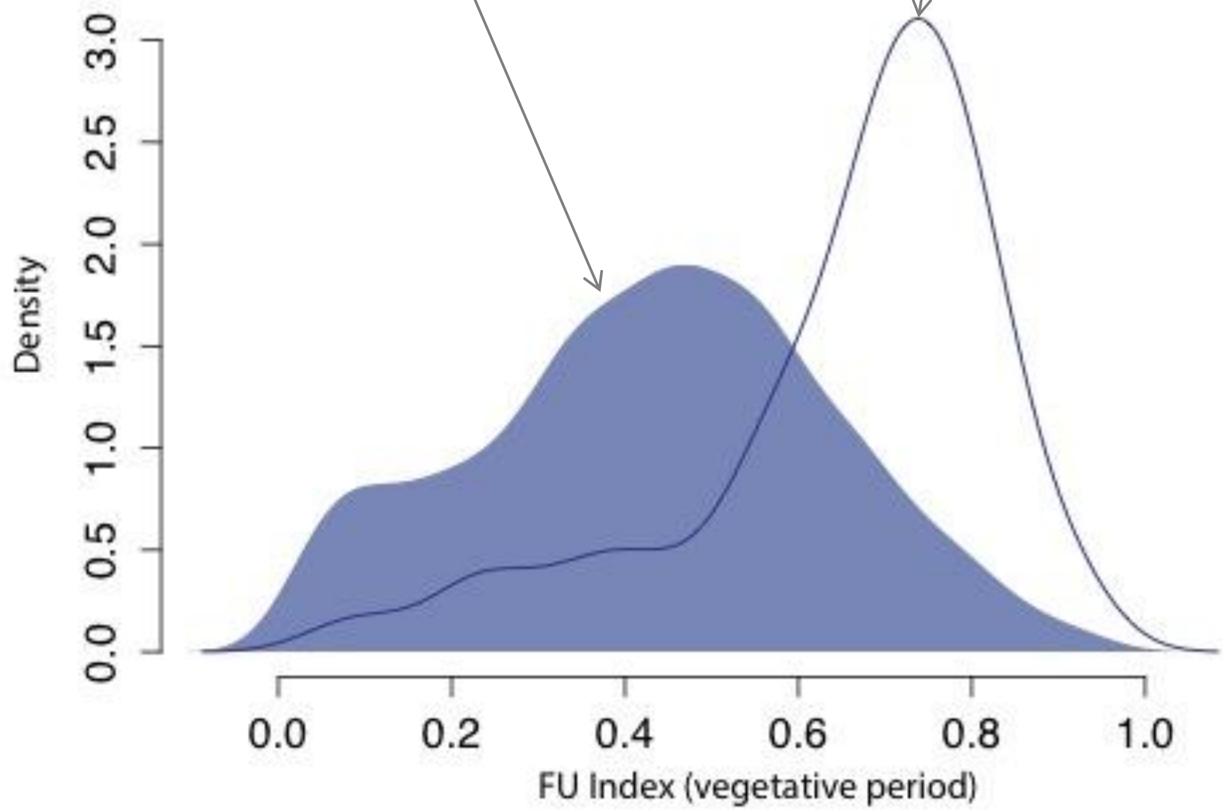
EXTREME AND NON-EXTREME INDICATOR DISTRIBUTIONS



AUC SCORE

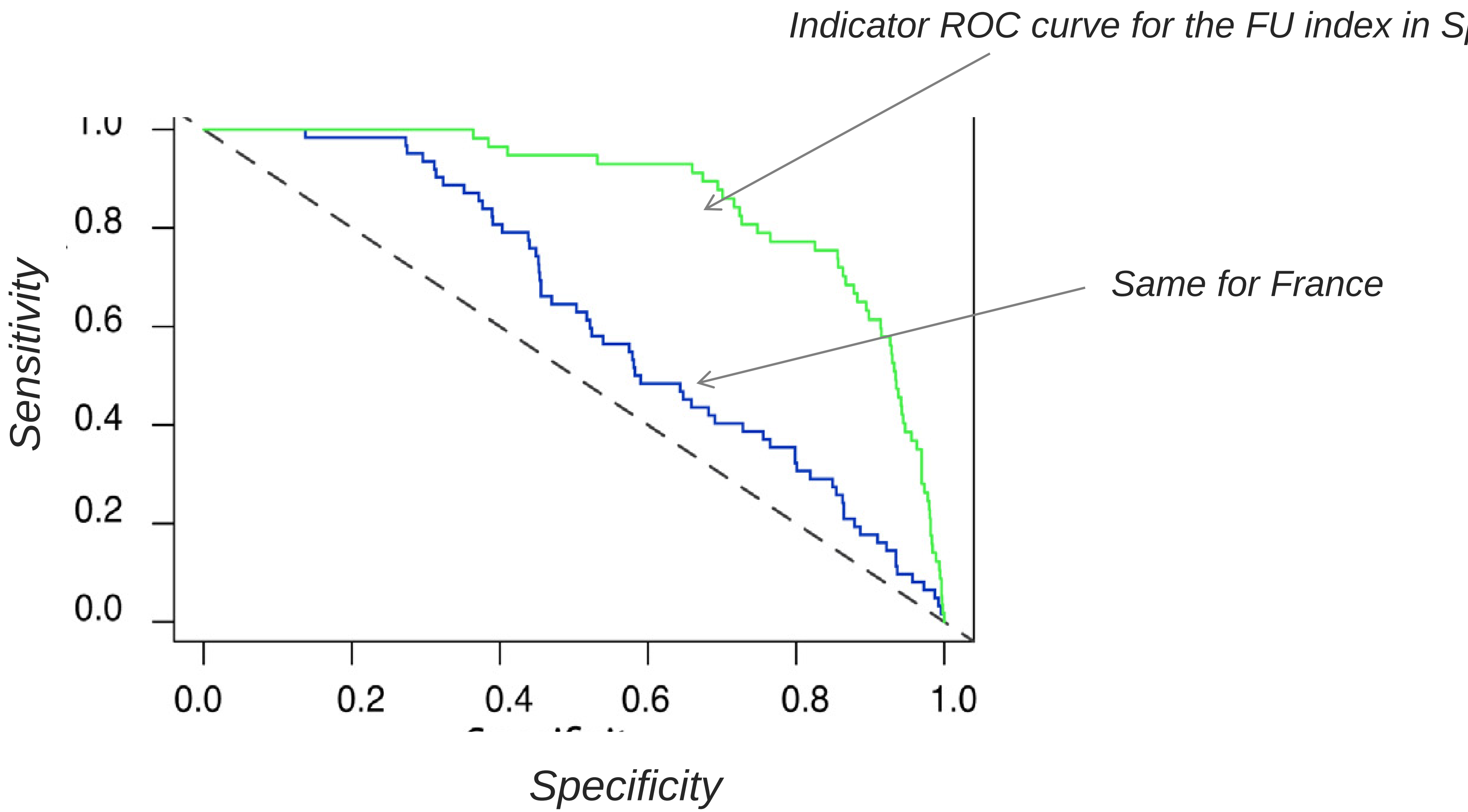
I_o : Distribution of Tmax indicator for “normal“ years

I_1 : Distribution of Tmax indicator for extreme yield loss years



$$P(I_1 > I_o) = AUC$$

EVALUATION OF ALL CLASSIFICATION RULES



YIELD TIME SERIES