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ModExtreme EU Project

Is it possible to predict extreme yield loss using climate indicators?

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Our objective

Investigate the usefulness of a large range of climate-based indicators to predict the occurrence of extreme yield loss

Yield data

Winter wheat

France: 93 *départements*, 1975-2014

Spain: 48 *provincias*, 1975-2014

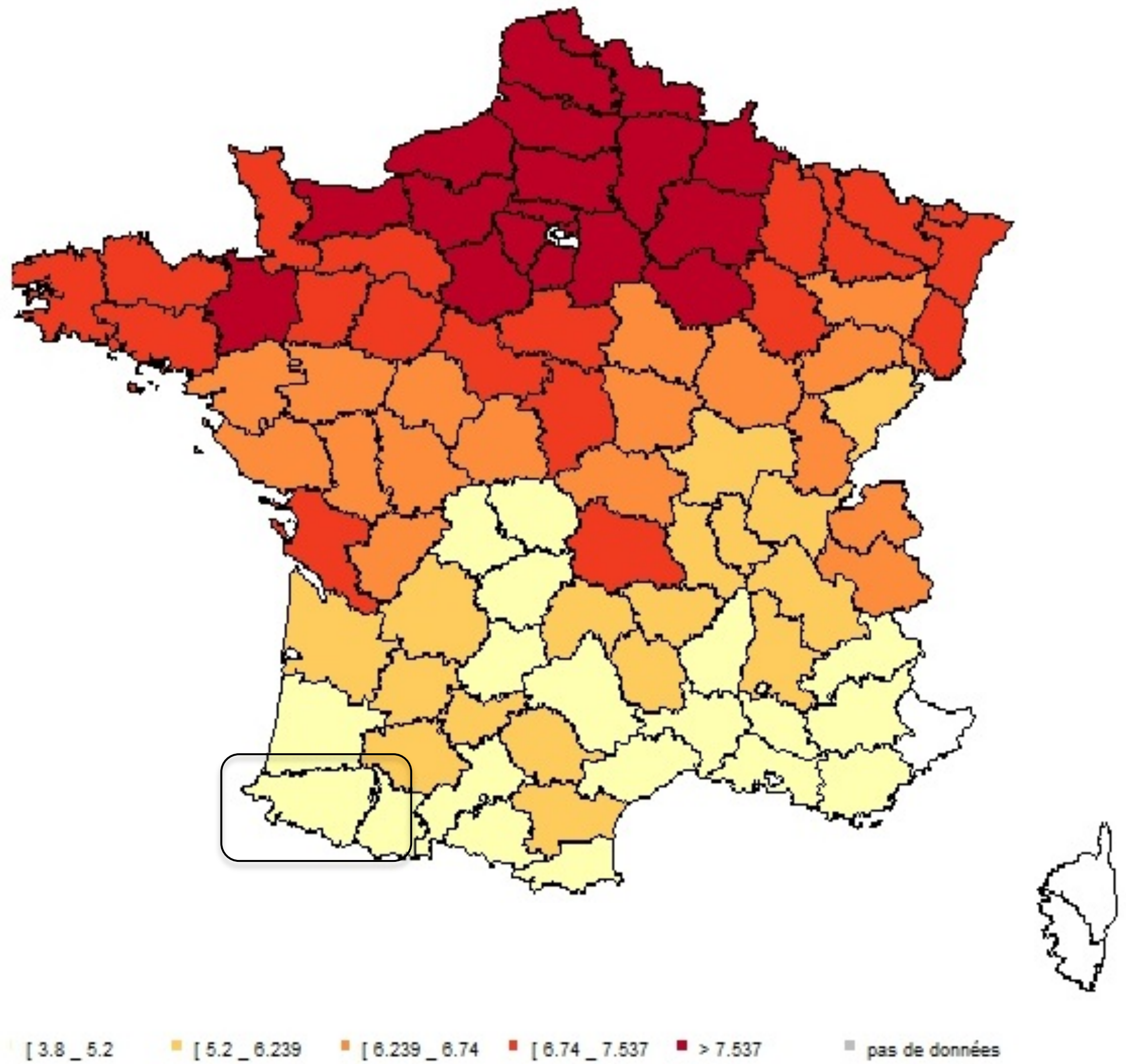
Non-irrigated maize

France: 93 *départements*, 1989-2013

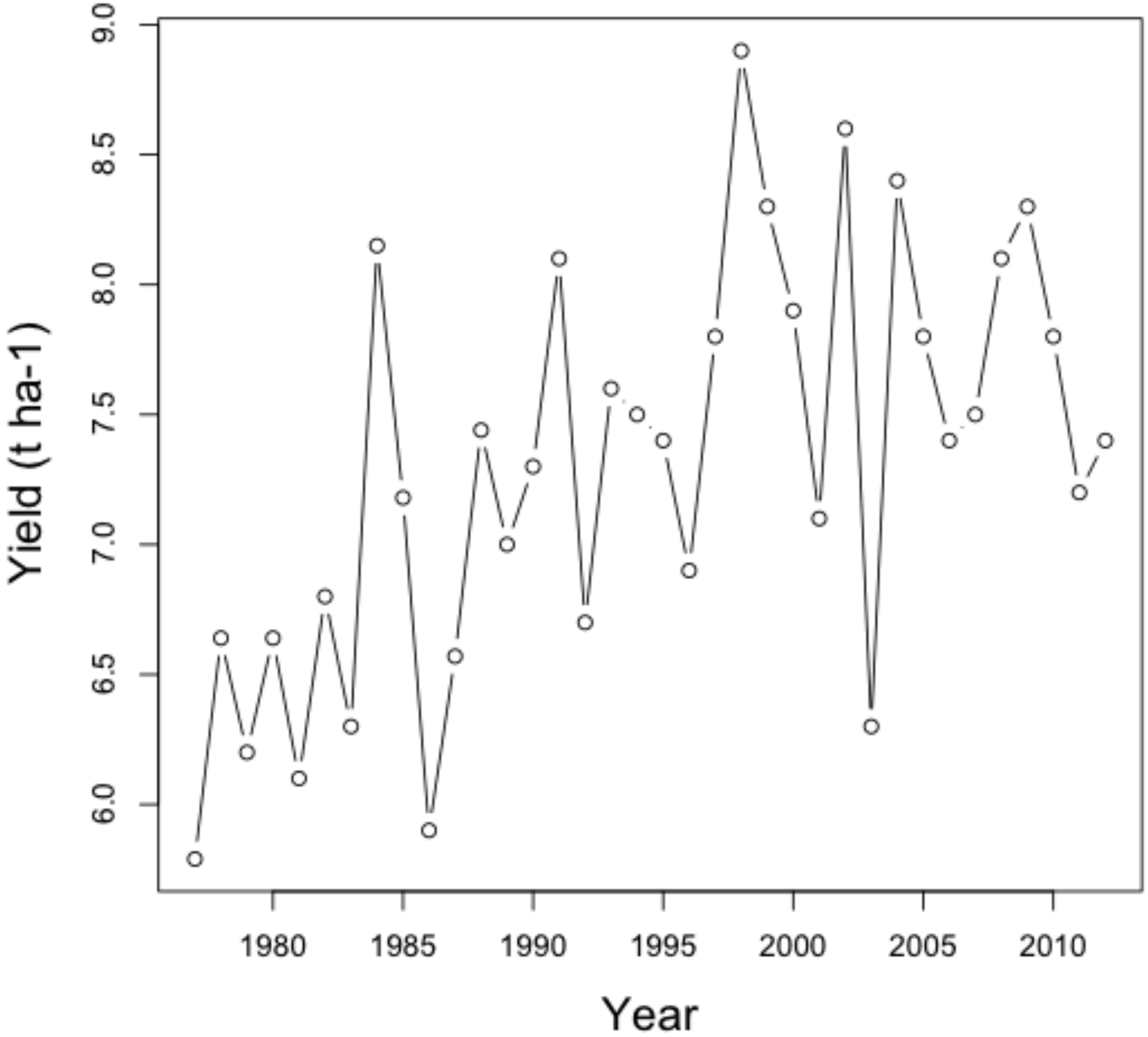
Spain: 48 *provincias*, 1975-2014

2013

Wheat yield (t ha^{-1})



Pyrénées-Atlantique

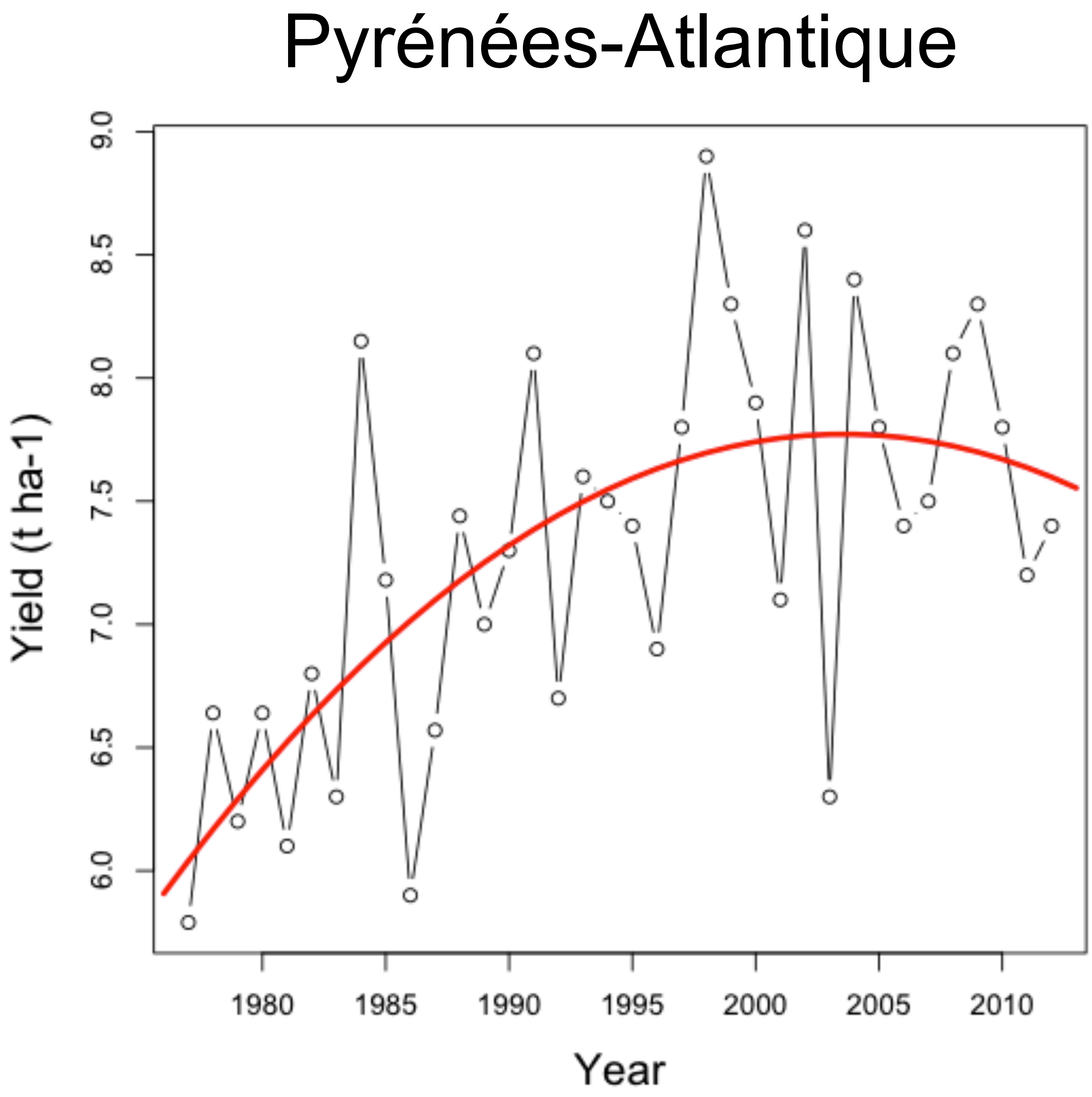


Yield time series decomposition

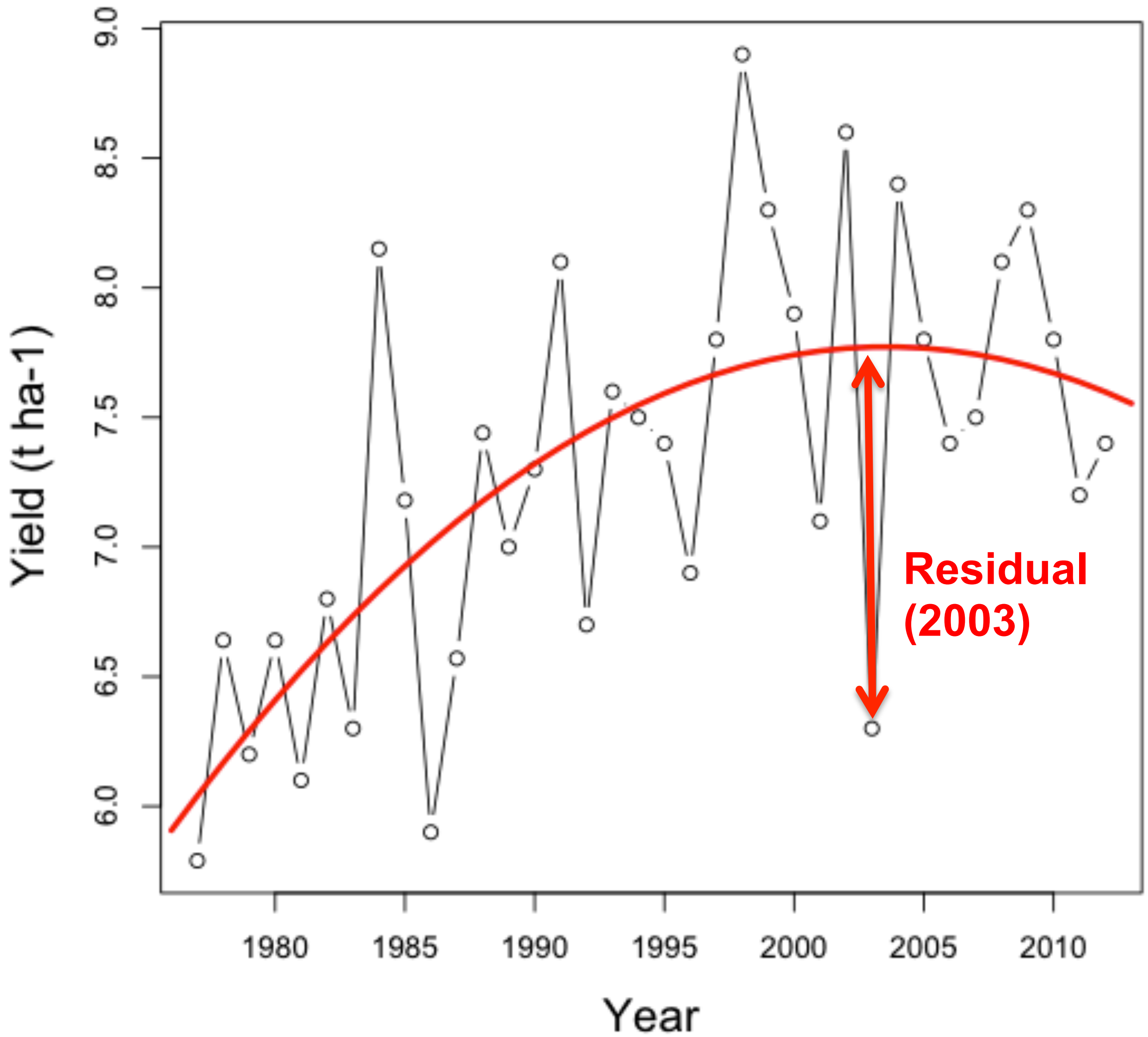
Yield (year t) = Trend (year t) + Residual (year t)

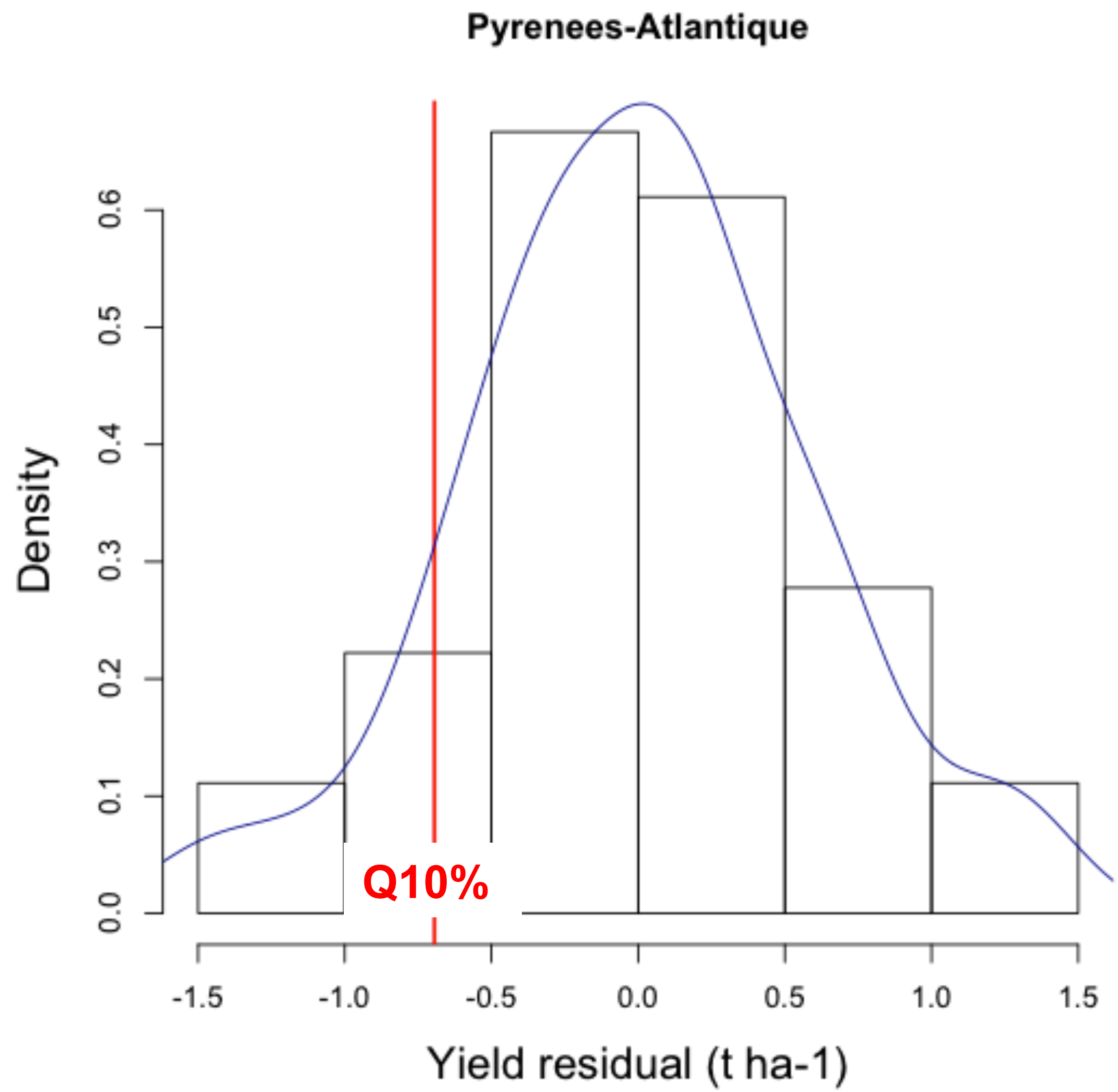
Two detrending methods:

- Polynomial regression,
- *loess* regression

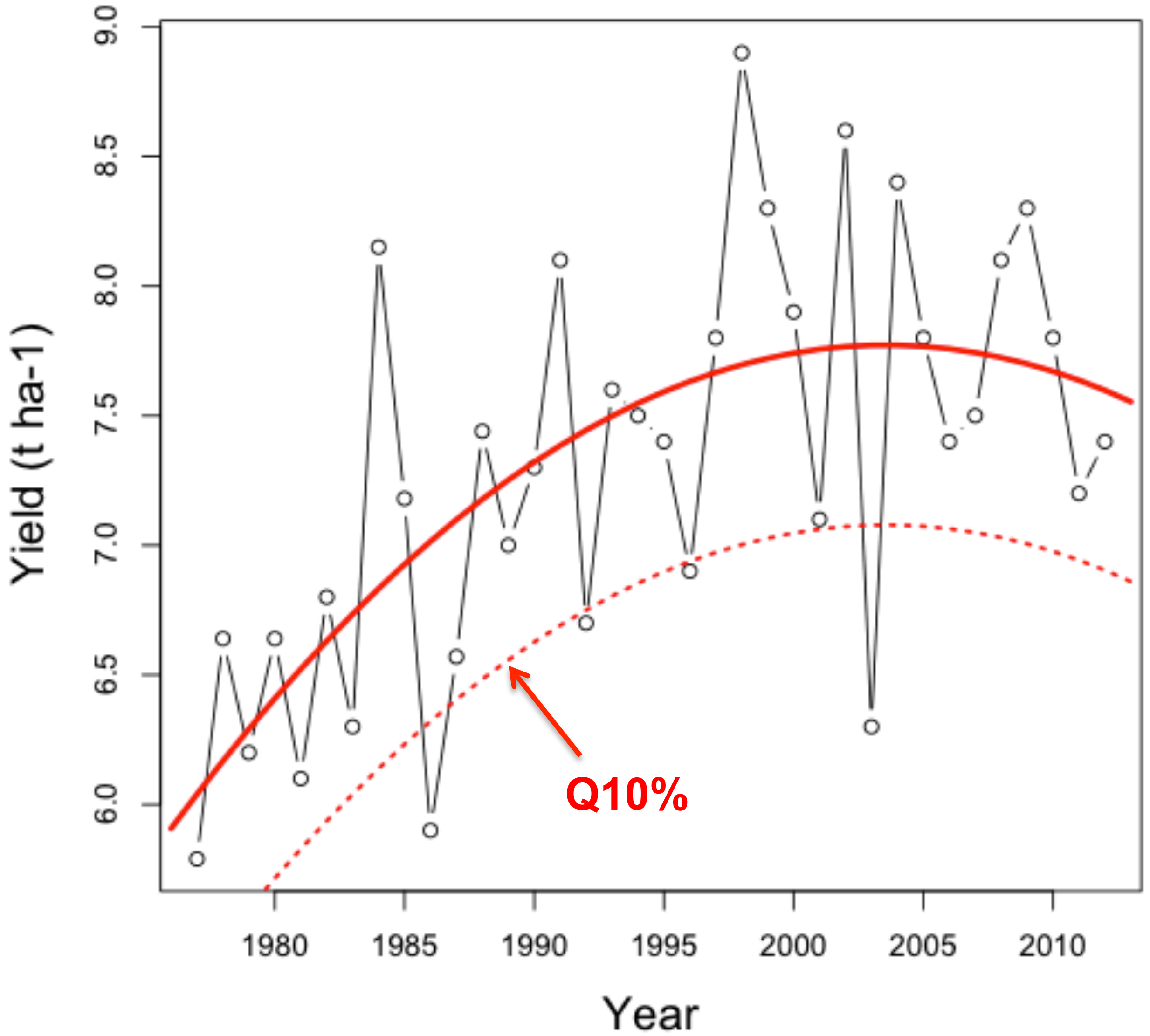

Pyrénées-Atlantique
Yield (t ha-1)
9.0
8.5
8.0
7.5
7.0
6.5
6.0
1980
1985
1990
1995
2000
2005
2010
Year

Pyrénées-Atlantique

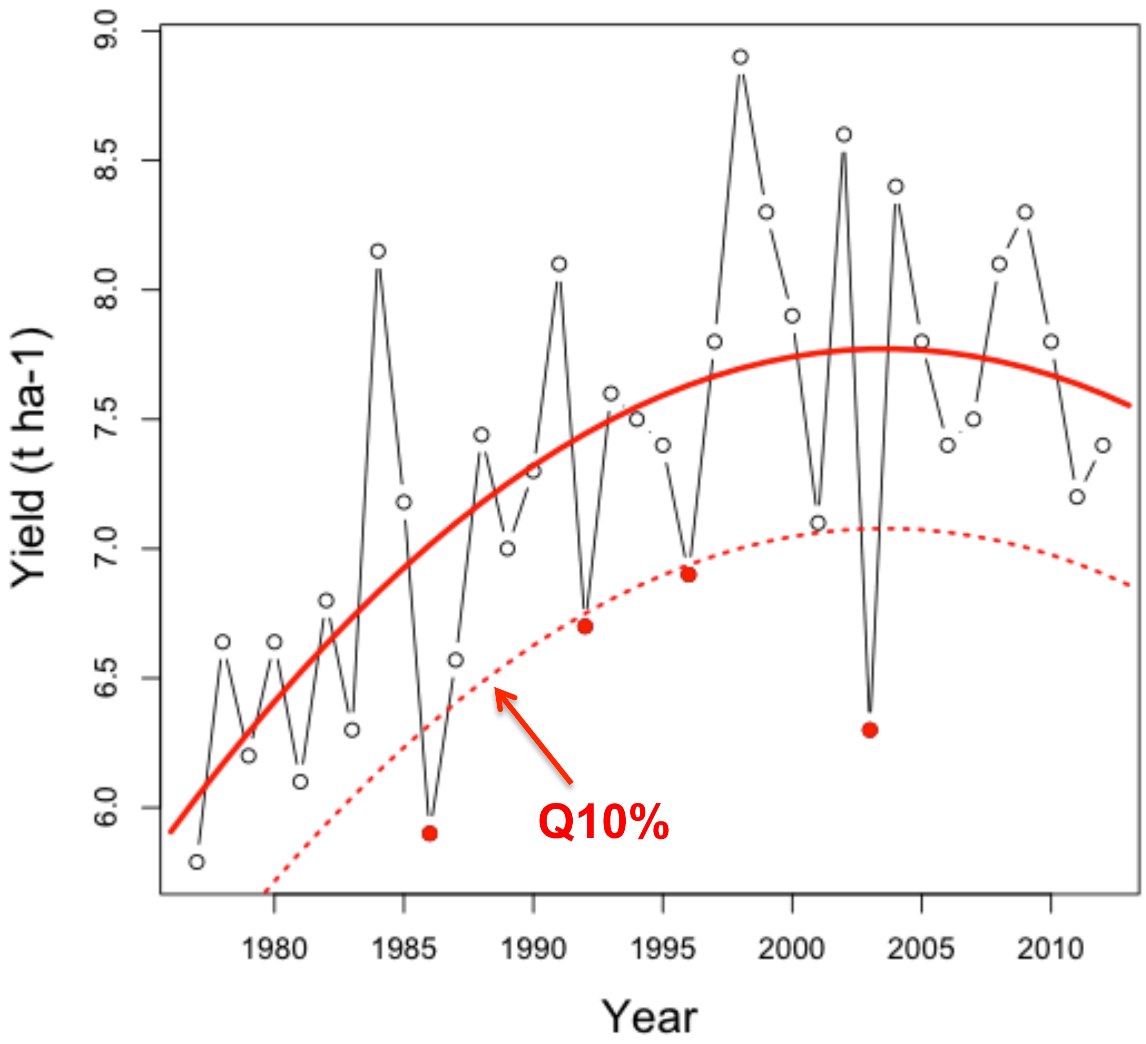



Pyrenees-Atlantique
Density
0.0
0.1
0.2
0.3
0.4
0.5
0.6
Q10%
-1.5
-1.0
-0.5
0.0
0.5
1.0
1.5
Yield residual (t ha-1)

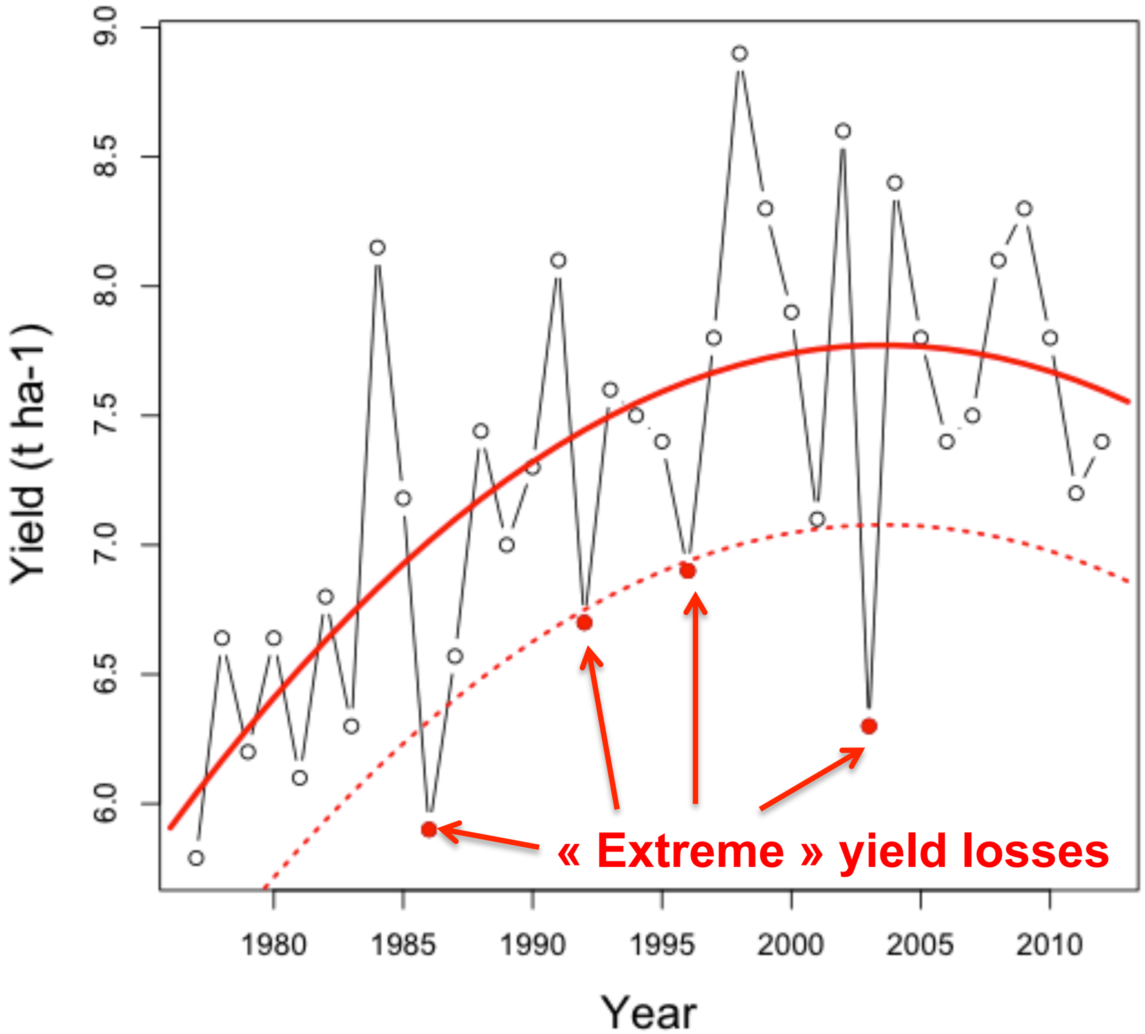
Pyrénées-Atlantique



Pyrénées-Atlantique



Pyrénées-Atlantique

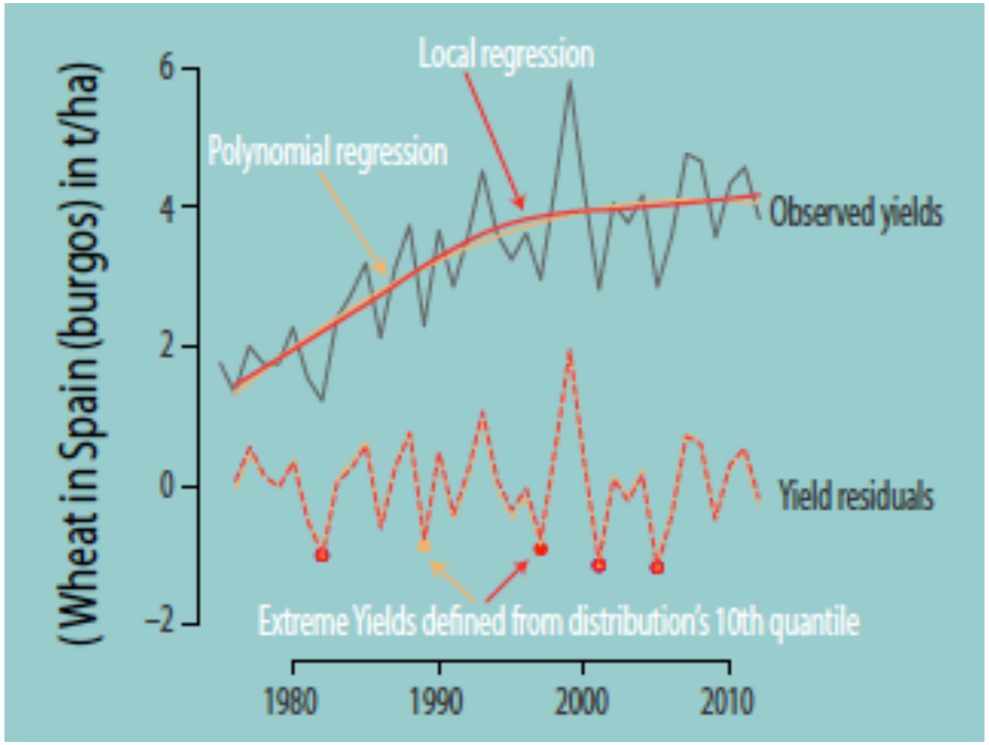


Yield data

Extreme yield losses were defined using

- two detrending methods (polynomial reg., loess)
- two percentiles (10th, 5th)

for two crops (wheat, maize) and all NUTS3 units in France and Spain.



(Wheat in Spain (burgos) in t/ha)
Local regression
Polynomial regression
Observed yields
Yield residuals
Extreme Yields defined from distribution's 10th quantile
6
4
2
0
−2
1980
1990
2000
2010

Climate data

- Weather data provided by the Joint Research Centre (Ispra, IT)
- Spatial resolution: 25km grid in France and Spain
- 1975-2014

Climate indicators

- Basic averaged climate variables
- Agroclimatic indices
- Crop model (WOFOST) outputs

Basic averaged climate variables

- Angot radiation (Radiation in MJ/m^2),
- Maximum and minimum temperatures (Tmax and Tmin in °C),
- Rainfall (precipitation in mm),
- Vapour pressure deficit (VPD in hPa),
- Evapotranspiration (ET_o mm/day) from a free water surface.

Averaged over

- Monthly periods
- One third of the growing season
- The totality of the growing season

Agroclimatic indices

- ARID (Agricultural Reference Index for Drought, Wolli et al, 2012)
- FU drought index (Fu, 1981; Zhang et al, 2008)
- Critical minimum temperature (Tmin.cr)
- Maximum temperature (Tmax.cr)
- Critical ARID (ARID.cr).
- North Atlantic Oscillation index

WOFOST outputs

- Potential and water-limited yields for maize and wheat
- Maize: July – August –September
- Wheat: April, May, June, July
- Yearly averages

NUTS3	Year	Climate indicator (Tmax)	Yield	Yield trend	Residual	Extreme
1	1989	20.5	5.2	5	+0.2	No
1	1990	28.1	3.1	5.5	-2.4	Yes
…	…	…	…	…	…	…
2	1989	22.7	5.4	5.8	-0.4	No

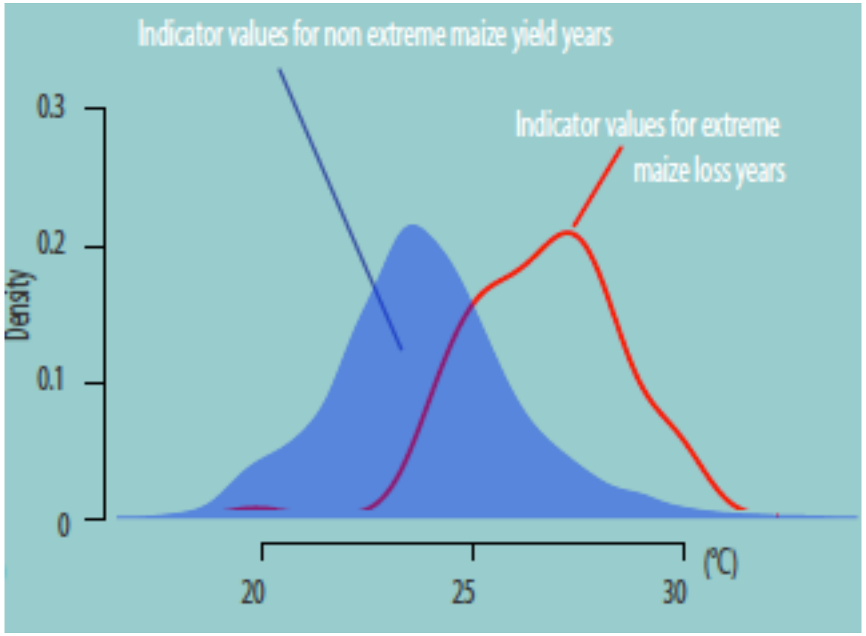
NUTS3	Year	Climate indicator (Tmax)	Yield	Yield trend	Residual	Extreme
1	1989	20.5	5.2	5	+0.2	No
1	1990	28.1	3.1	5.5	-2.4	Yes
…	…	…	…	…	…	…
2	1989	22.7	5.4	5.8	-0.4	No

NUTS3	Climate indicator (Tmax)	Extreme
1	28.1	Yes
1	26.5	Yes
…	…	…
2	27.8	Yes

NUTS3	Climate indicator (Tmax)	Extreme
1	23.1	No
1	21.5	No
…	…	…
2	22.7	No

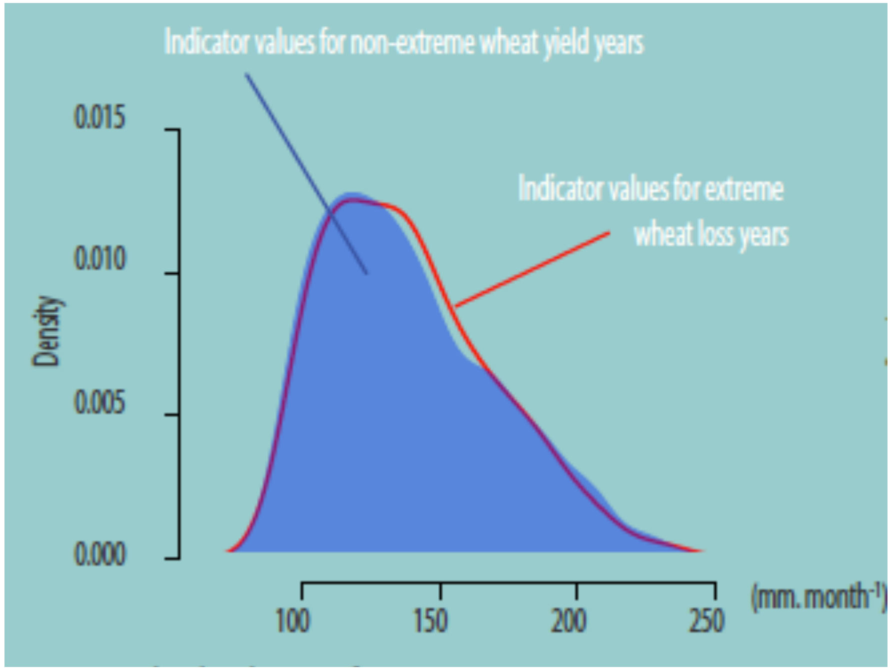
Distributions of **Tmax (June-July)** in NUTS3 units in France for

- non-extreme wheat yield years
- extreme wheat yield years



Distributions of **evapotranspiration (autumn)** in NUTS3 units in Spain for

- non-extreme wheat yield years
- extreme wheat yield years



Comparison of the indicators by ROC analysis

NUTS3	Climate indicator (Tmax)	Extreme
1	28.1	Yes
1	26.5	Yes
…	…	…
2	27.8	Yes

NUTS3	Climate indicator (Tmax)	Extreme
1	23.1	No
1	21.5	No
…	…	…
2	22.7	No

Comparison of the indicators by ROC analysis

NUTS3	Climate indicator (Tmax)	Extreme
1	28.1	Yes
1	26.5	Yes
…	…	…
2	27.8	Yes

↓

Rate of true positive (sensitivity)

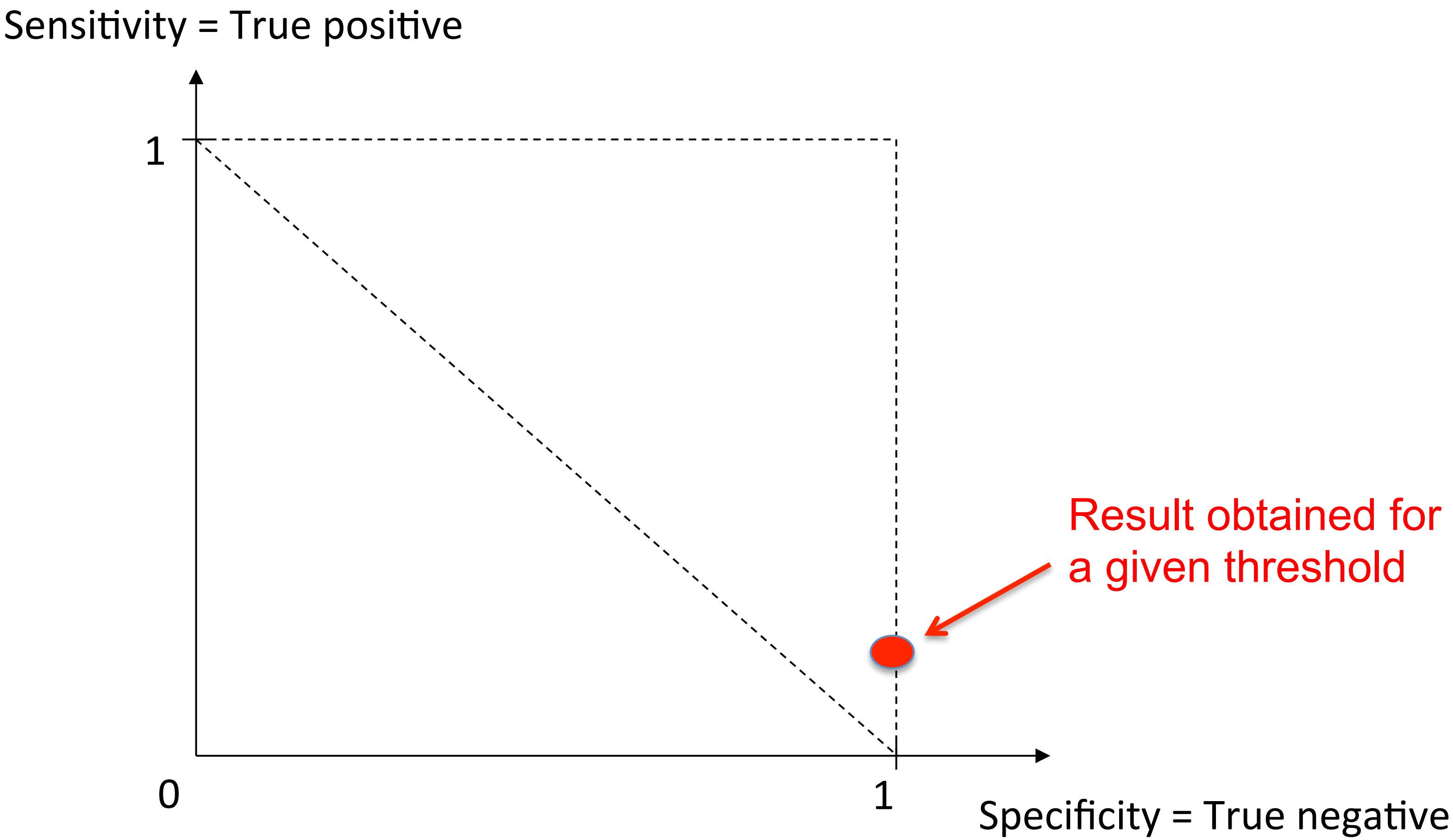
Prob($T_{max} > T$ | Extreme loss)

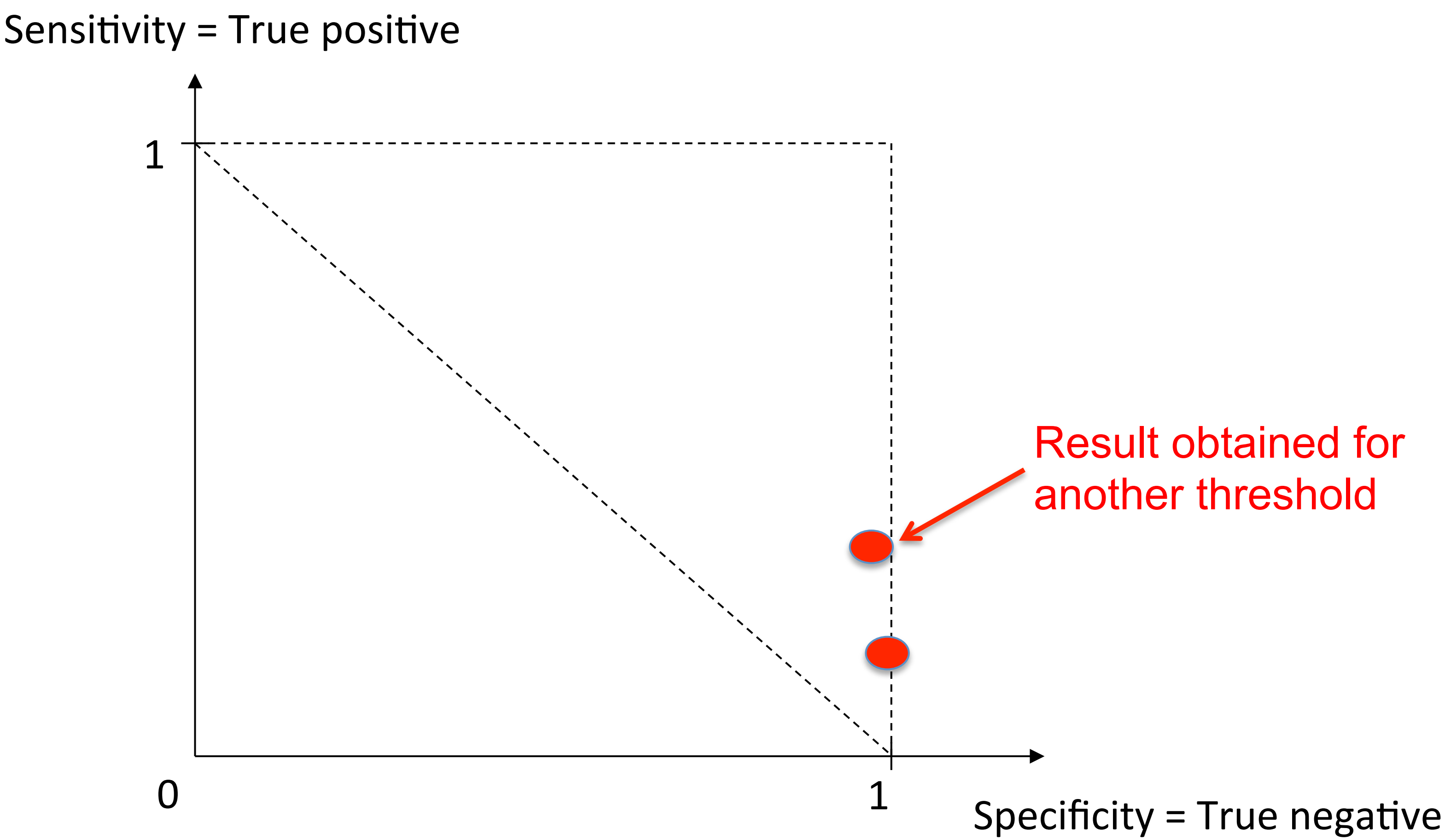
NUTS3	Climate indicator (Tmax)	Extreme
1	23.1	No
1	21.5	No
…	…	…
2	22.7	No

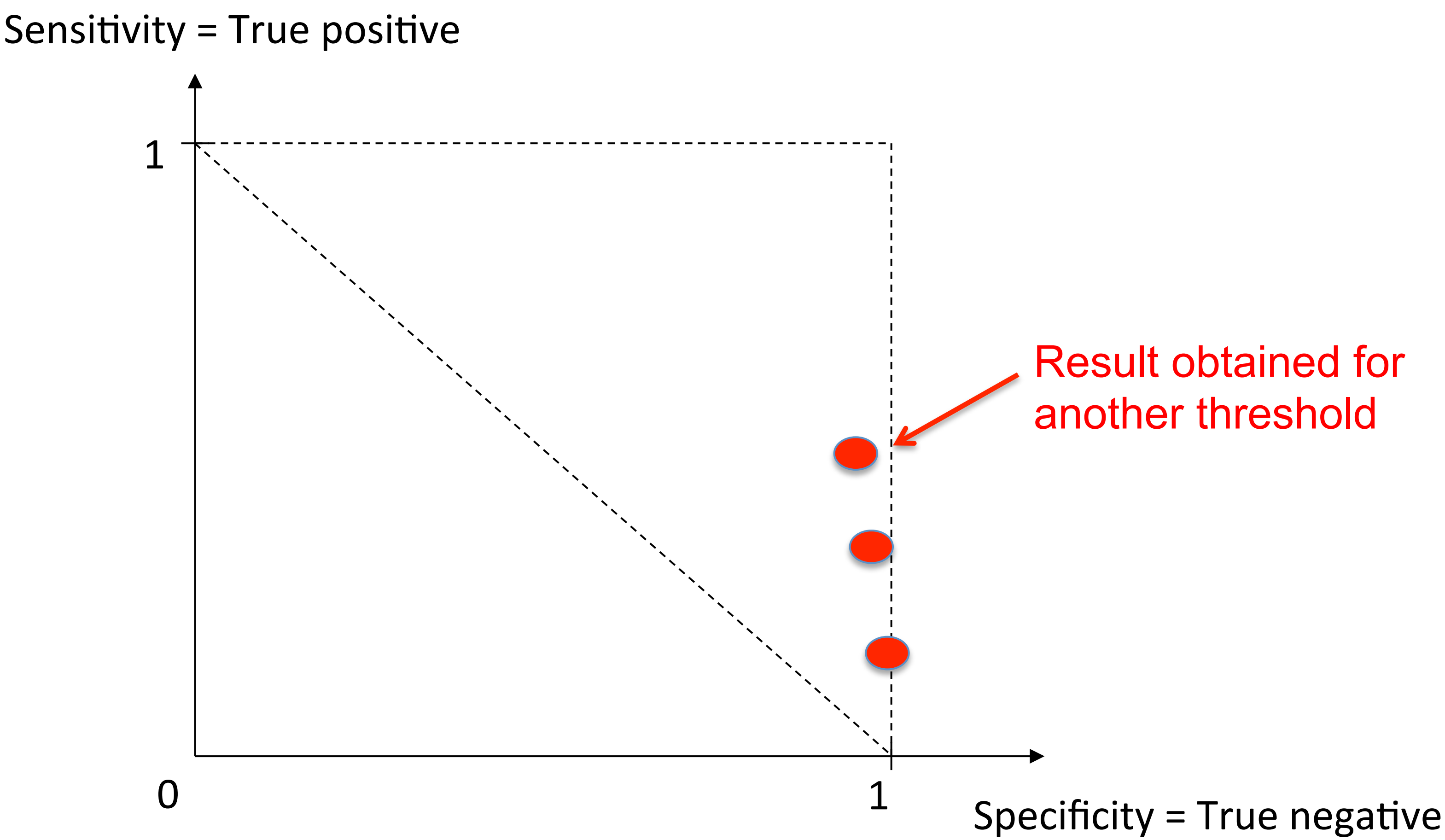
↓

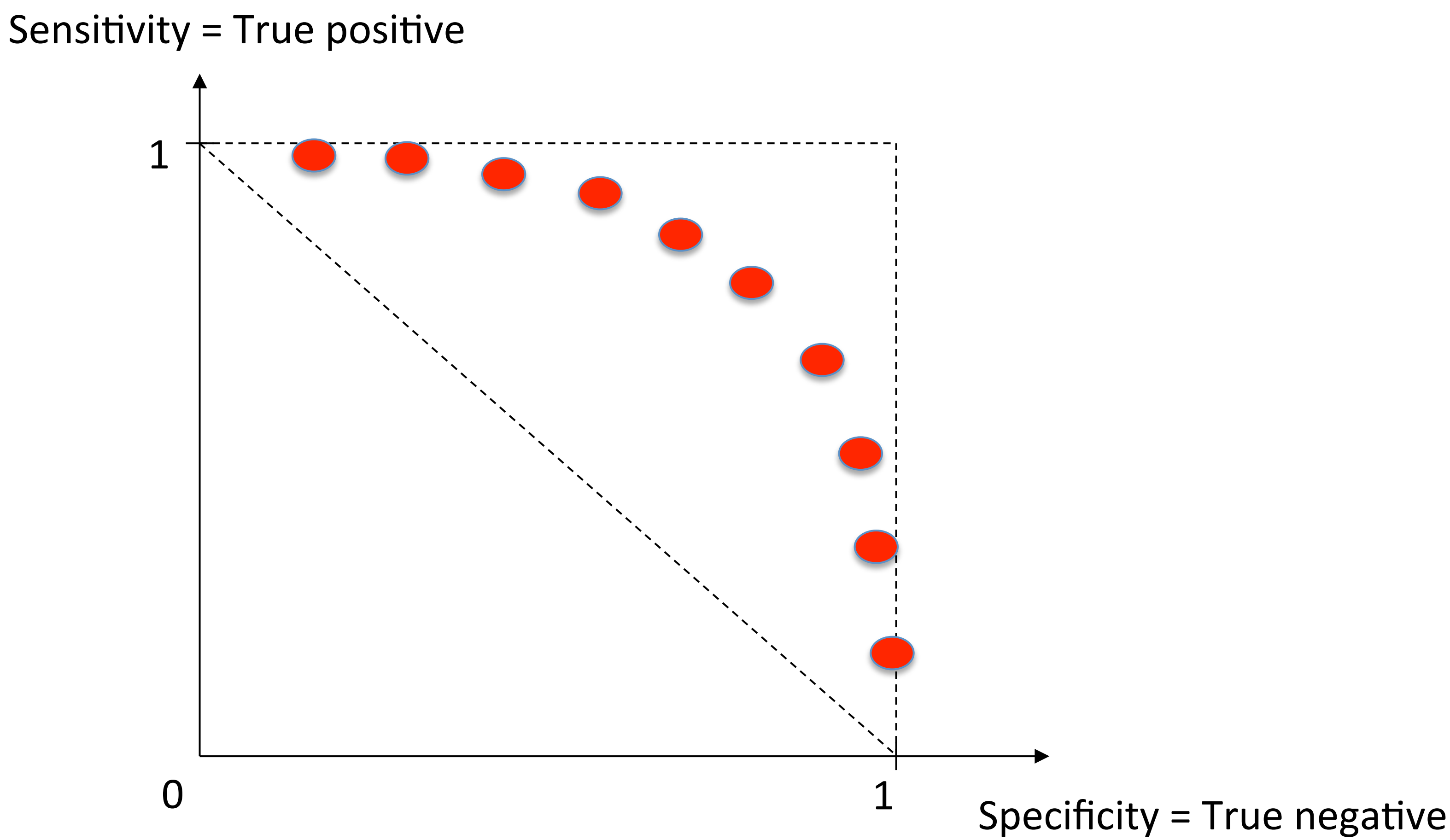
Rate of true negative (specificity)

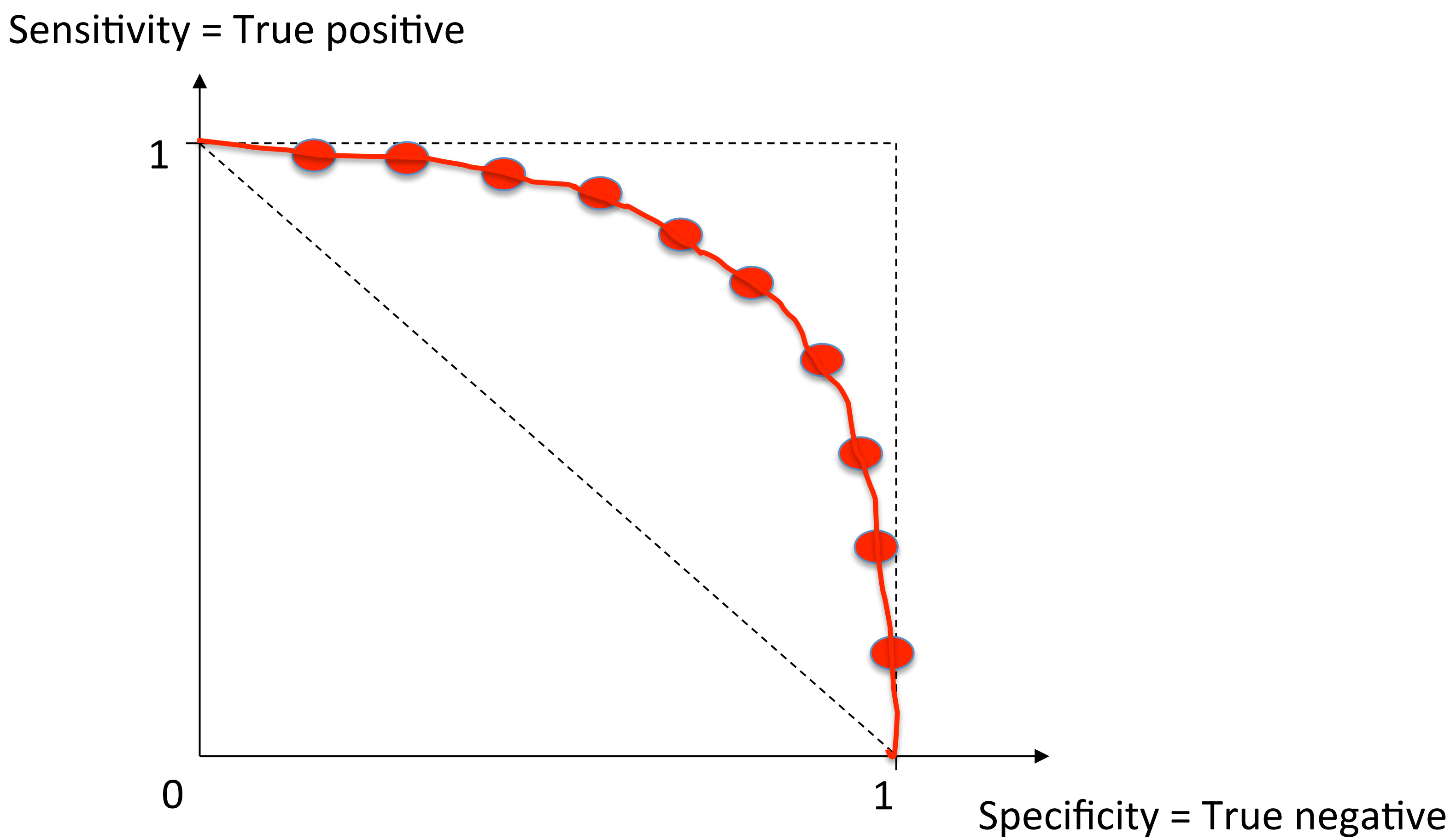
Prob($T_{max} < T$ | Non-extreme loss)


Sensitivity = True positive
1
0
1
Specificity = True negative
Result obtained for
a given threshold


Sensitivity = True positive
1
Result obtained for
another threshold
0
1
Specificity = True negative

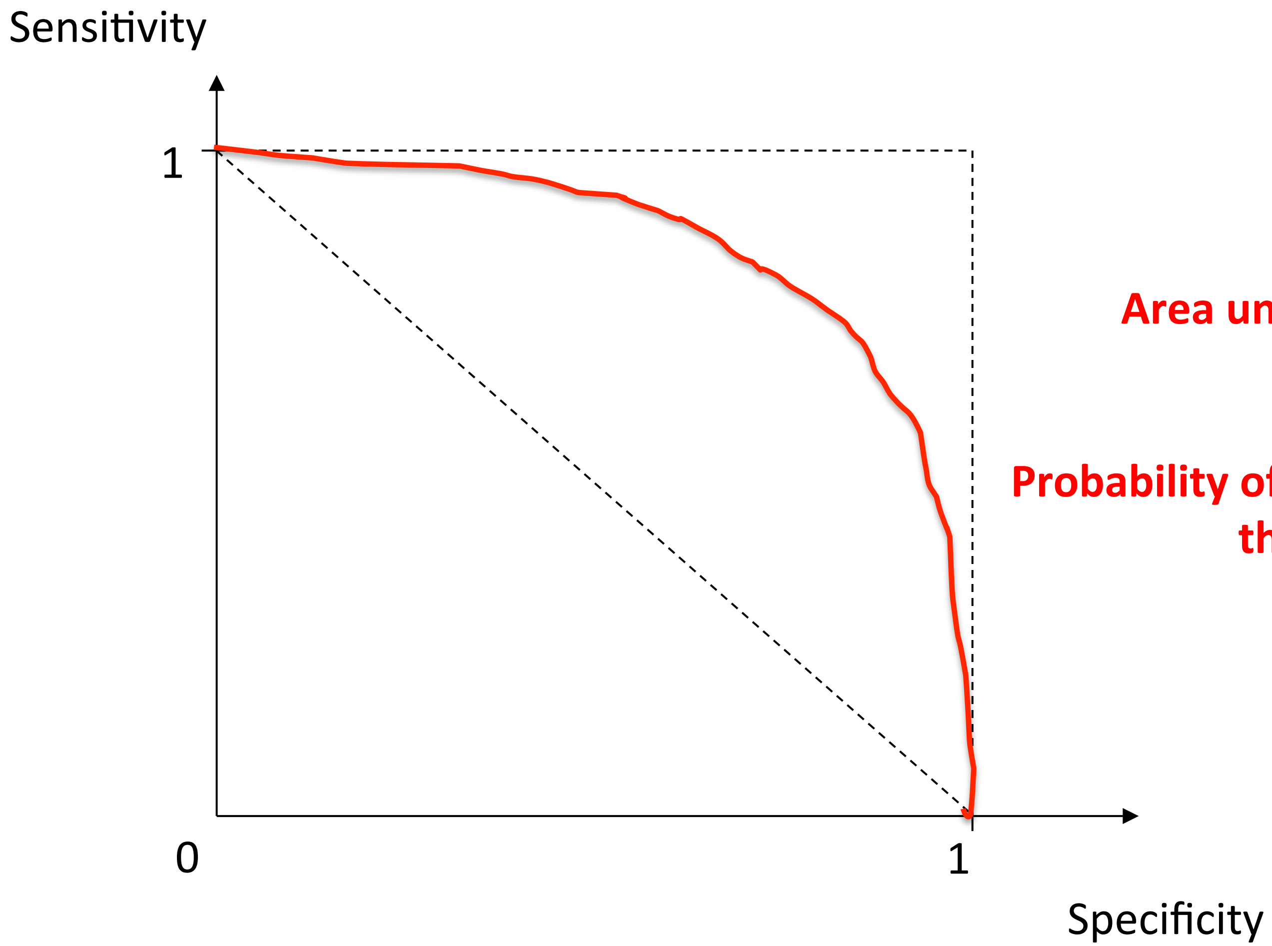

Sensitivity = True positive
1
Result obtained for another threshold
0
1
Specificity = True negative


Sensitivity = True positive
1
0
1
Specificity = True negative



Sensitivity = True positive
1
0
1
Specificity = True negative

Indicator 1: The classification rule is much better than random classification

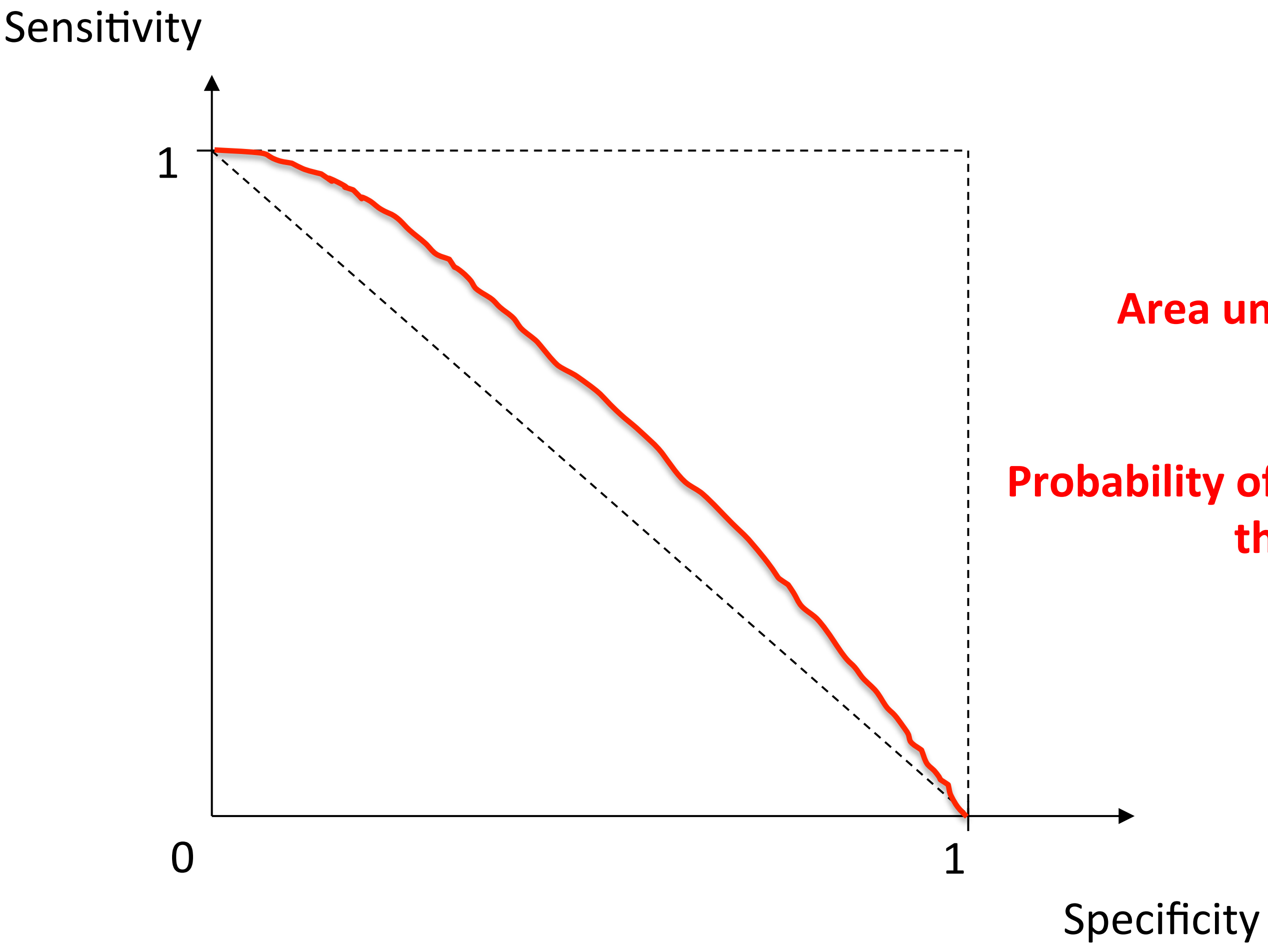


Area under the curve

=

Probability of correct ranking by the index

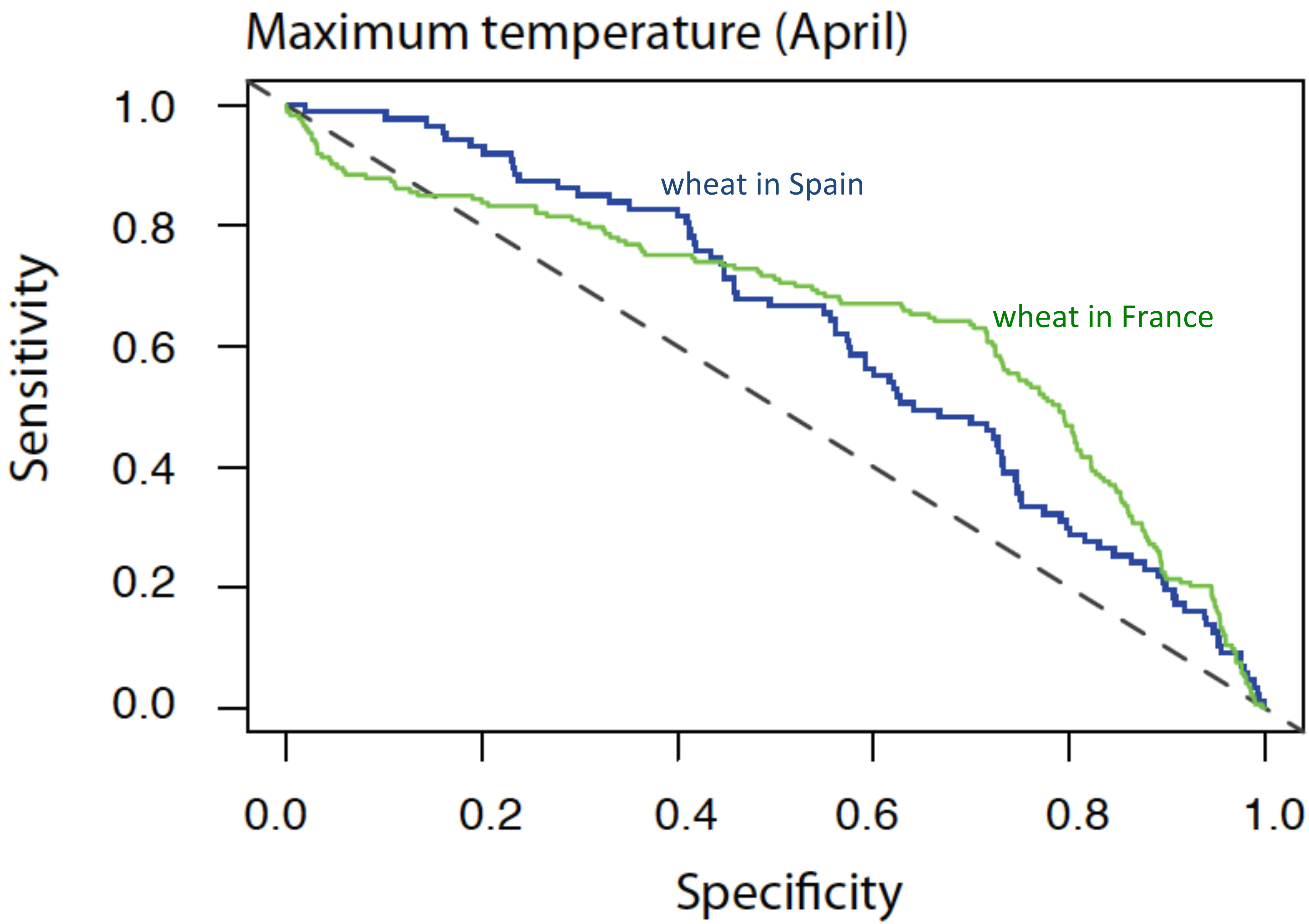
Indicator 2: The classification rule is not much better than random classification

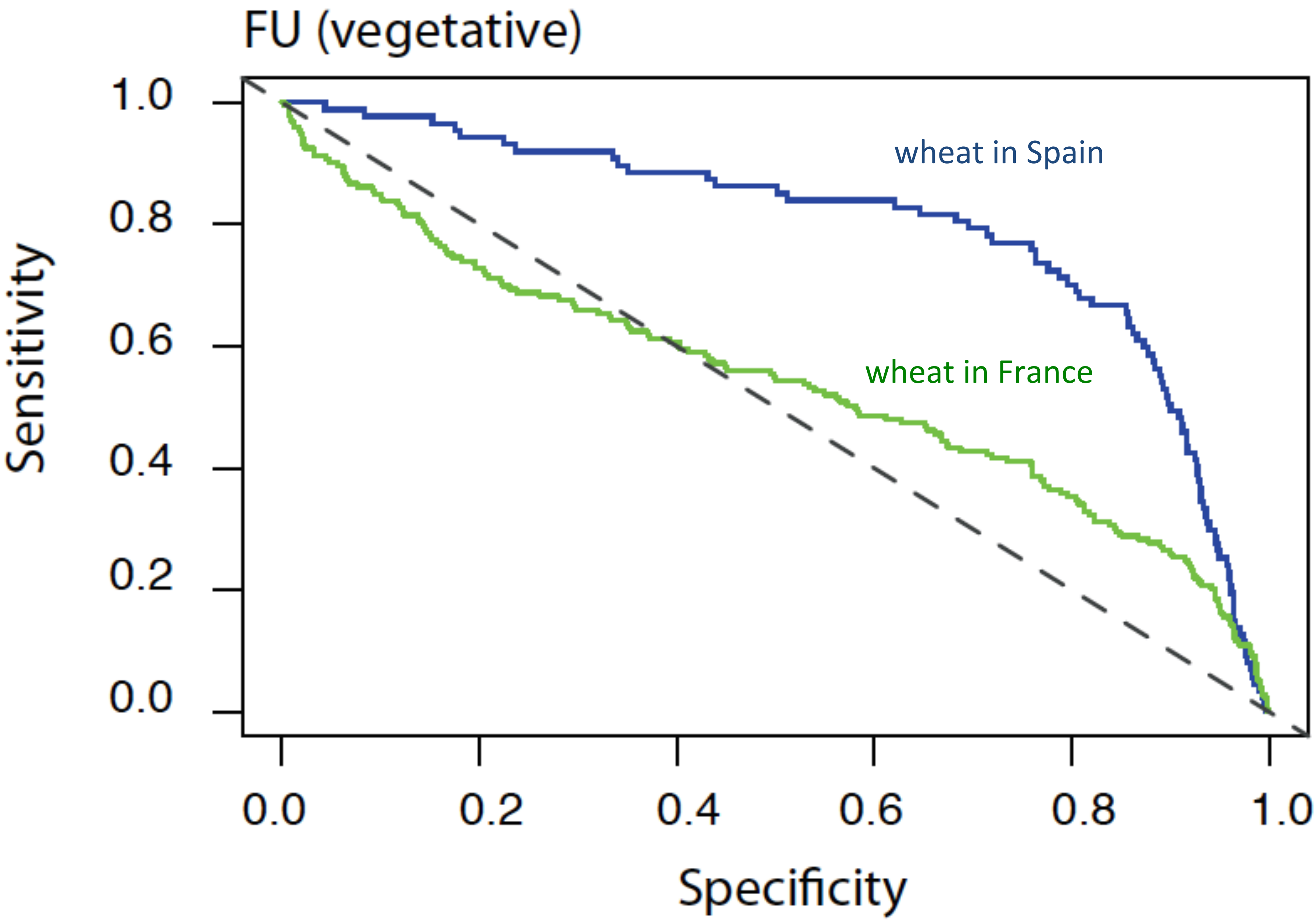


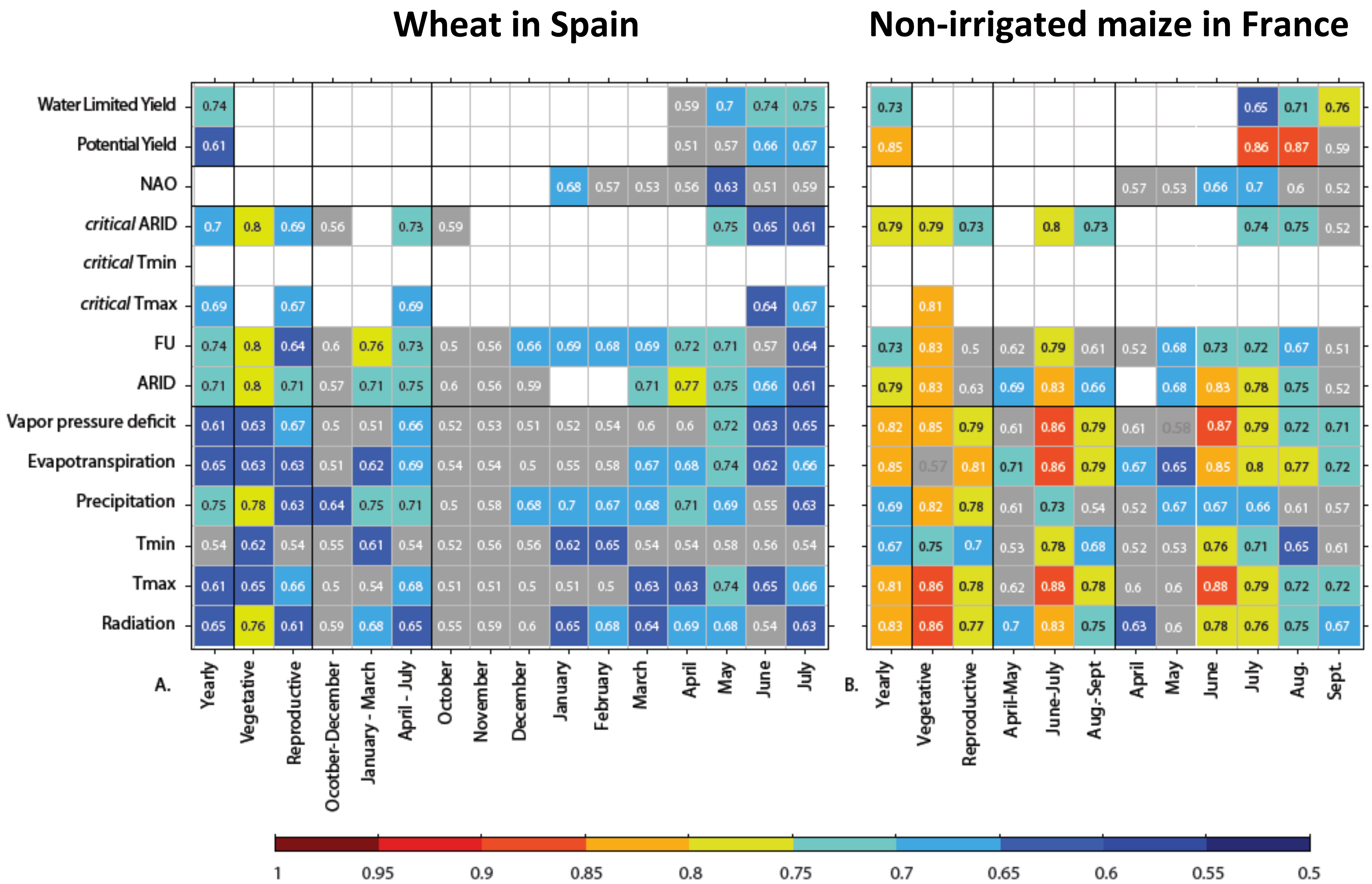
Area under the curve

=

Probability of correct ranking by the index


Maximum temperature (April)
wheat in Spain
wheat in France
1.0
0.8
0.6
0.4
0.2
0.0
Sensitivity
0.0
0.2
0.4
0.6
0.8
1.0
Specificity


FU (vegetative)
Sensitivity
1.0
0.8
0.6
0.4
0.2
0.0
Specificity
0.0
0.2
0.4
0.6
0.8
1.0
wheat in Spain
wheat in France

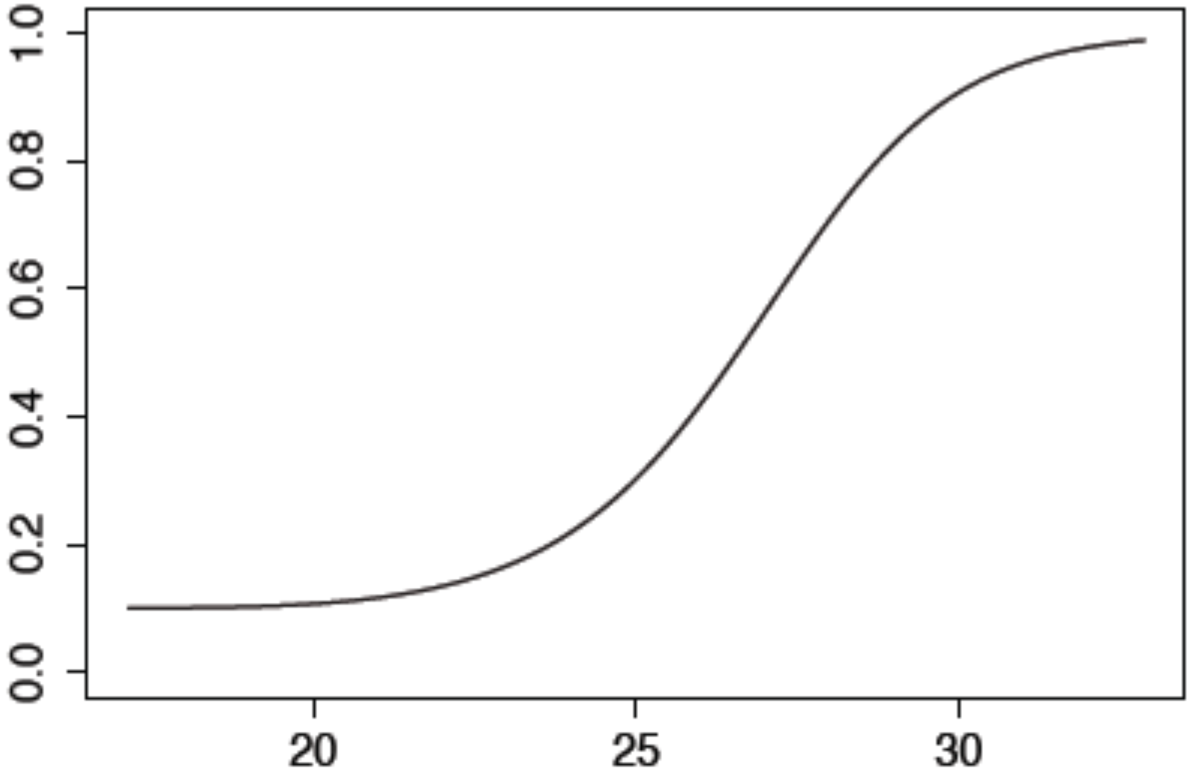

Wheat in Spain
Non-irrigated maize in France
Water Limited Yield
Potential Yield
NAO
critical ARID
critical Tmin
critical Tmax
FU
ARID
Vapor pressure deficit
Evapotranspiration
Precipitation
Tmin
Tmax
Radiation
0.74 0.59 0.7 0.74 0.75
0.61 0.51 0.57 0.66 0.67
0.68 0.57 0.53 0.56 0.63 0.51 0.59
0.7 0.8 0.69 0.56 0.73 0.59 0.75 0.65 0.61
0.69 0.67 0.69 0.64 0.67
0.74 0.8 0.64 0.6 0.76 0.73 0.5 0.56 0.66 0.69 0.68 0.69 0.72 0.71 0.57 0.64
0.71 0.8 0.71 0.57 0.71 0.75 0.6 0.56 0.59 0.71 0.77 0.75 0.66 0.61
0.61 0.63 0.67 0.5 0.51 0.66 0.52 0.53 0.51 0.52 0.54 0.6 0.6 0.72 0.63 0.65
0.65 0.63 0.63 0.51 0.62 0.69 0.54 0.54 0.5 0.55 0.58 0.67 0.68 0.74 0.62 0.66
0.75 0.78 0.63 0.64 0.75 0.71 0.5 0.58 0.68 0.7 0.67 0.68 0.71 0.69 0.55 0.63
0.54 0.62 0.54 0.55 0.61 0.54 0.52 0.56 0.56 0.62 0.65 0.54 0.54 0.58 0.56 0.54
0.61 0.65 0.66 0.5 0.54 0.68 0.51 0.51 0.5 0.51 0.5 0.63 0.63 0.74 0.65 0.66
0.65 0.76 0.61 0.59 0.68 0.65 0.55 0.59 0.6 0.65 0.68 0.64 0.69 0.68 0.54 0.63
A.
Yearly
Vegetative
Reproductive
October-December
January - March
April - July
October
November
December
January
February
March
April
May
June
July
0.73 0.65 0.71 0.76
0.85 0.86 0.87 0.59
0.57 0.53 0.66 0.7 0.6 0.52
0.79 0.79 0.73 0.8 0.73 0.74 0.75 0.52
0.81
0.73 0.83 0.5 0.62 0.79 0.61 0.52 0.68 0.73 0.72 0.67 0.51
0.79 0.83 0.63 0.69 0.83 0.66 0.68 0.83 0.78 0.75 0.52
0.82 0.85 0.79 0.61 0.86 0.79 0.61 0.58 0.87 0.79 0.72 0.71
0.85 0.57 0.81 0.71 0.86 0.79 0.67 0.65 0.85 0.8 0.77 0.72
0.69 0.82 0.78 0.61 0.73 0.54 0.52 0.67 0.67 0.66 0.61 0.57
0.67 0.75 0.7 0.53 0.78 0.68 0.52 0.53 0.76 0.71 0.65 0.61
0.81 0.86 0.78 0.62 0.88 0.78 0.6 0.6 0.88 0.79 0.72 0.72
0.83 0.86 0.77 0.7 0.83 0.75 0.63 0.6 0.78 0.76 0.75 0.67
B.
Yearly
Vegetative
Reproductive
April-May
June-July
Aug.-Sept
April
May
June
July
Aug.
Sept.
1
0.95
0.9
0.85
0.8
0.75
0.7
0.65
0.6
0.55
0.5

Posterior probability of extreme yield loss occurence

$$\Pr\,(Extreme\ loss/\ Climate\ indicator > T)$$

$$= \frac{Sensitivity(T) \times Pr(Extreme\ loss)}{Sensitivity(T) \times Pr(Extreme\ loss) + (1 - Specificity(T)) \times (1 - \Pr\,(Extreme\ loss))}$$

Probability of extreme yield loss



T_{max} in June for non-irrigated maize in France (°C)

Conclusions

- No single indicator performs systematically well but several show acceptable scores.
- There is no obvious relationship between the level of complexity of a given indicator and its accuracy.
- Basic climatic variables often outperform mechanistic models
- Maximum temperatures and, later in the growing season, potential yield simulations rank highest for both crop species in France.
- Drought indices perform well in Spain for wheat and maize.
- We provide a relation linking the most accurate indicator threshold values to the probability of extreme yield loss