Scoping Meeting Agricultural Risk Assessment

7 – 9 February 2017 – Boulder, Colorado

Day 1. Incorporating Drought and the Agricultural Sector in the GAR Global Risk Model

A Conceptual Model for Assessing Global Risk in the Agriculture Sector

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February 7, 2017

INGENIAR

Drought Risk Assessment

- ✓ *The objective is to develop a drought risk model to estimate the economical losses in the agricultural sector, for all the countries in the world (or as many as possible).*

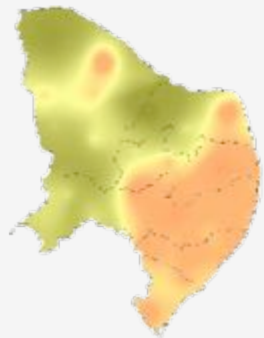
- ✓ *The proposed methodology aims to quantify the loss in production (yield) of crops exposed to droughts.*

- ✓ *Any other adverse effect of droughts is not considered within the scope of this methodology.*

- ✓ *The expected outcome is the risk assessment in terms of probabilistic metrics (AAL, PML, LEC) at country level.*

Probabilistic Risk Assessment

HAZARD

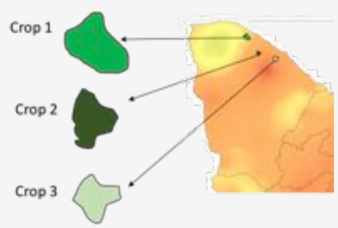


Set of stochastic scenarios

- Based on historical climate data
- Probabilistic representation
- Spatially distributed
- Time series

- All return periods are included
- Possibility of including CC trends

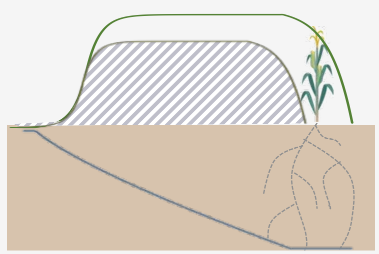
EXPOSURE



Cultivated land units

- Location
- Crop type and seasonality
- Cultivated area
- Production cost
- Soil characteristics

VULNERABILITY



Crop yield response to water

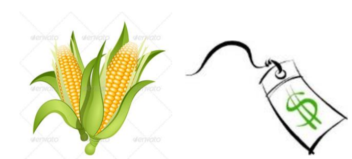
- Crop characteristics
- Crop calendar
- Climate time series
- Loss in potential production

RISK

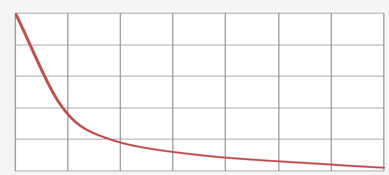
Damage

Loss

Production | Economic



Metrics



- Loss exceedance curve (LEC)
- Average annual loss (AAL)
- Probable maximum loss (PML)

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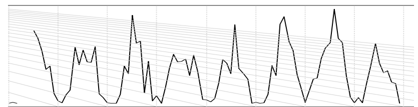
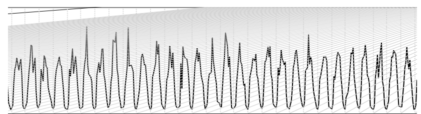
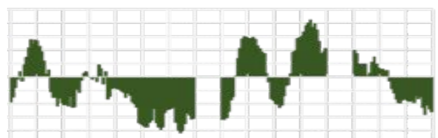
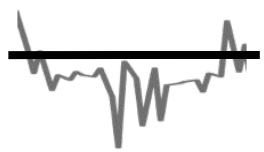
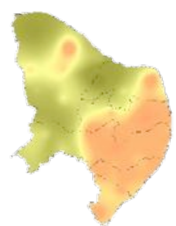
Drought Hazard

Hazard

Inputs	**Historic records**		*Station or satellite data of temperature and precipitation time series*
Outputs	**Future series**		*Stochastic generation of future time series*
	Drought indicator		*Calculated in several time bases. Multiple indicators*
	Drought events		*Spatial and temporal drought event definition*
	Integrated hazard maps		*For communication purposes (not required for risk assessment)*

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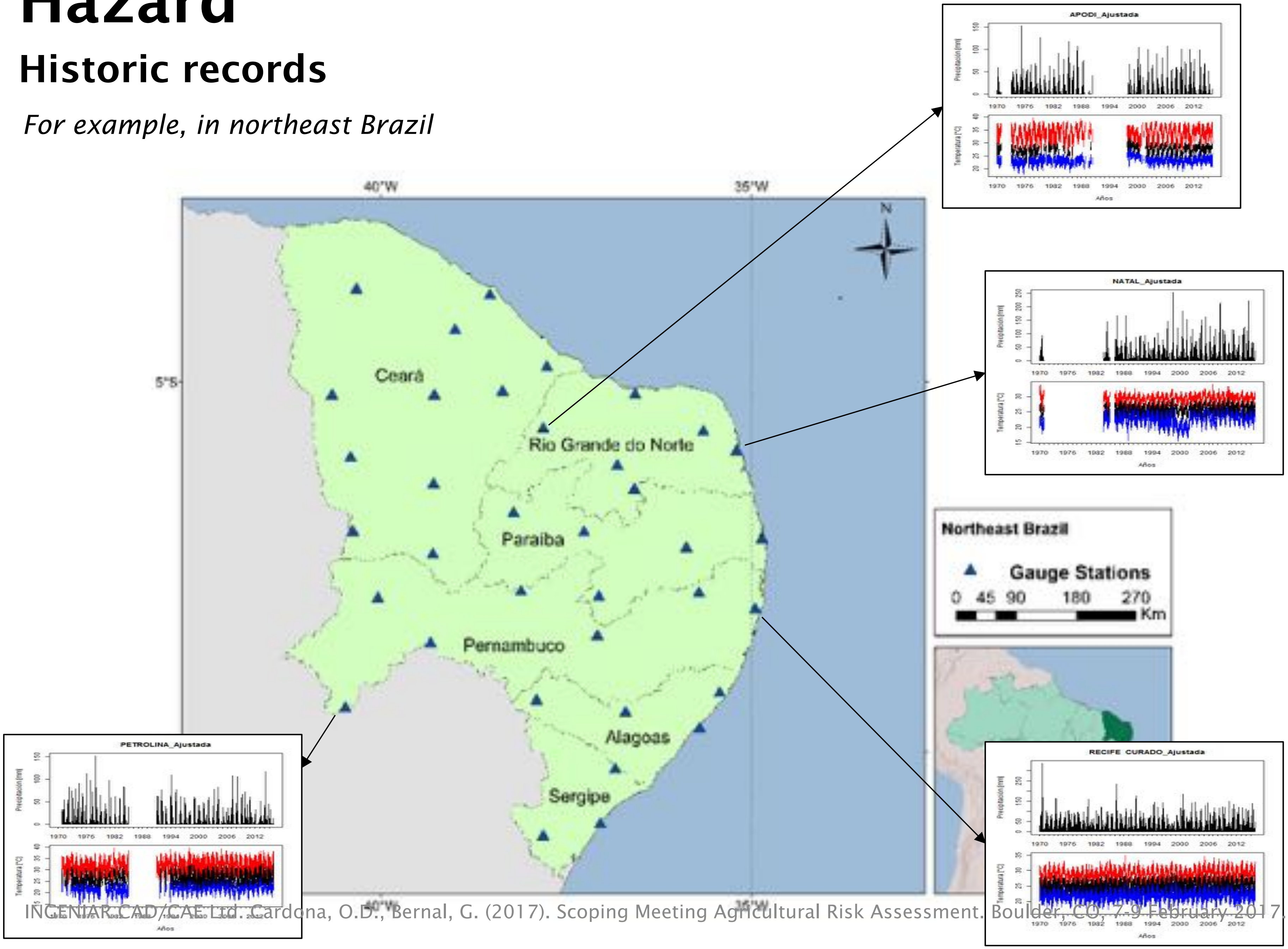
Hazard

Historic records

For example, in northeast Brazil



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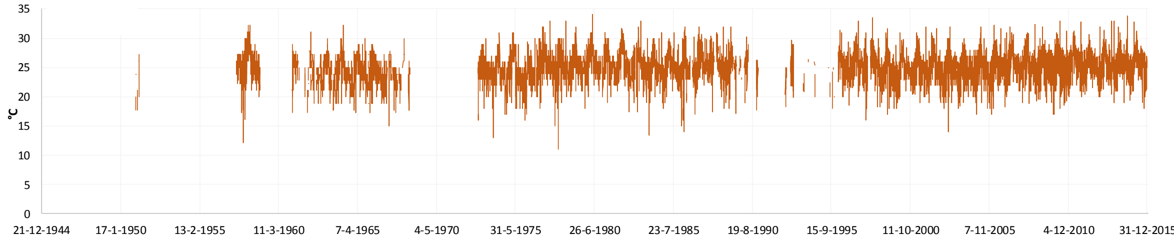
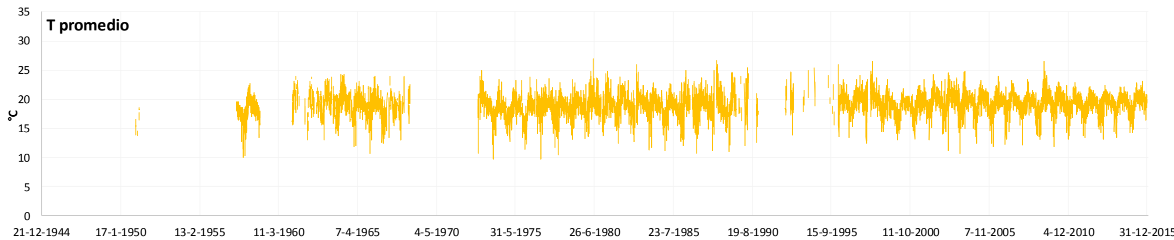
Hazard

Historic time series completion

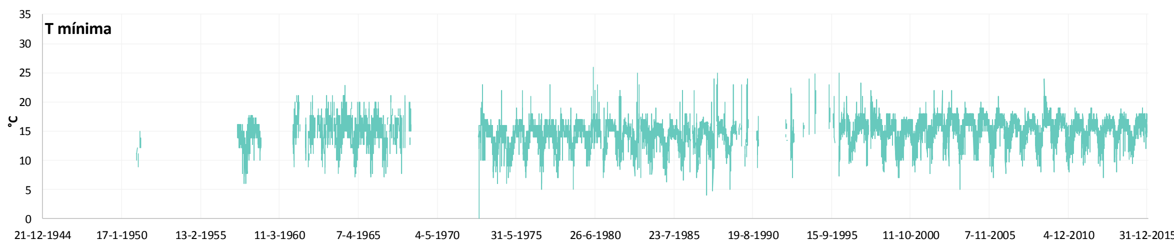
T max [°C]



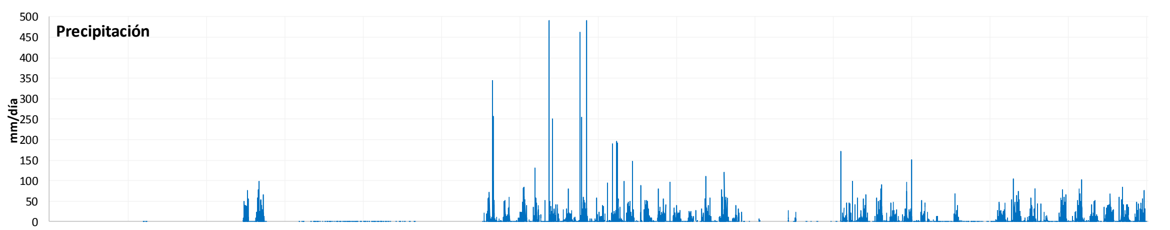
T mean [°C]



T min [°C]



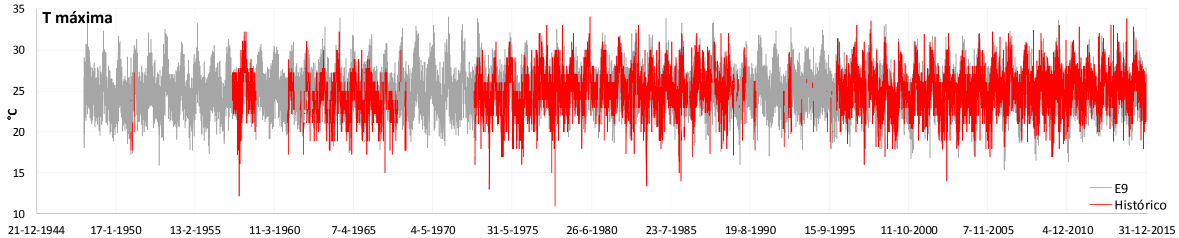
Rainfall [mm/day]



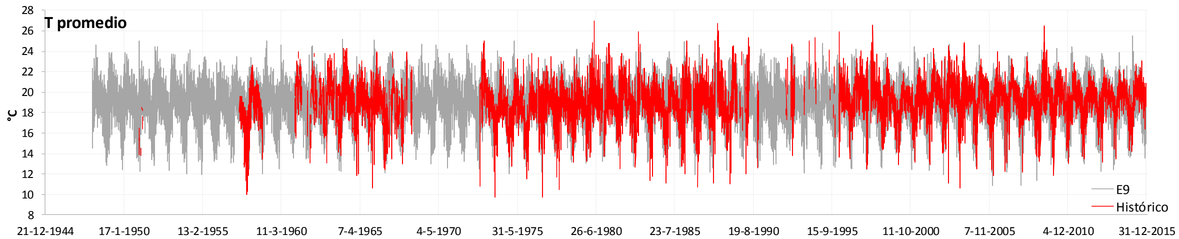
Hazard

Historic time series completion

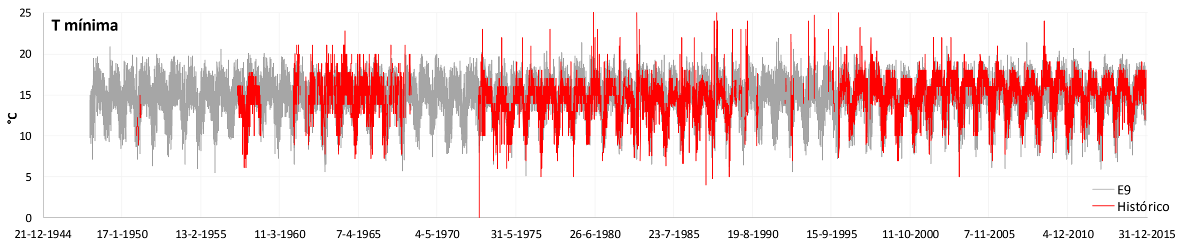
T max [°C]



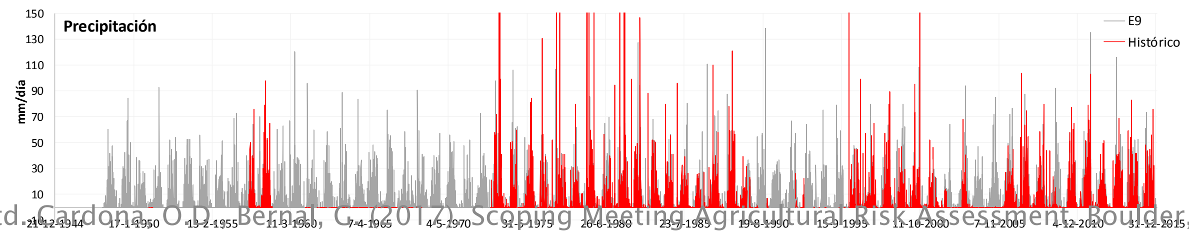
T mean [°C]



T min [°C]



Rainfall [mm/day]

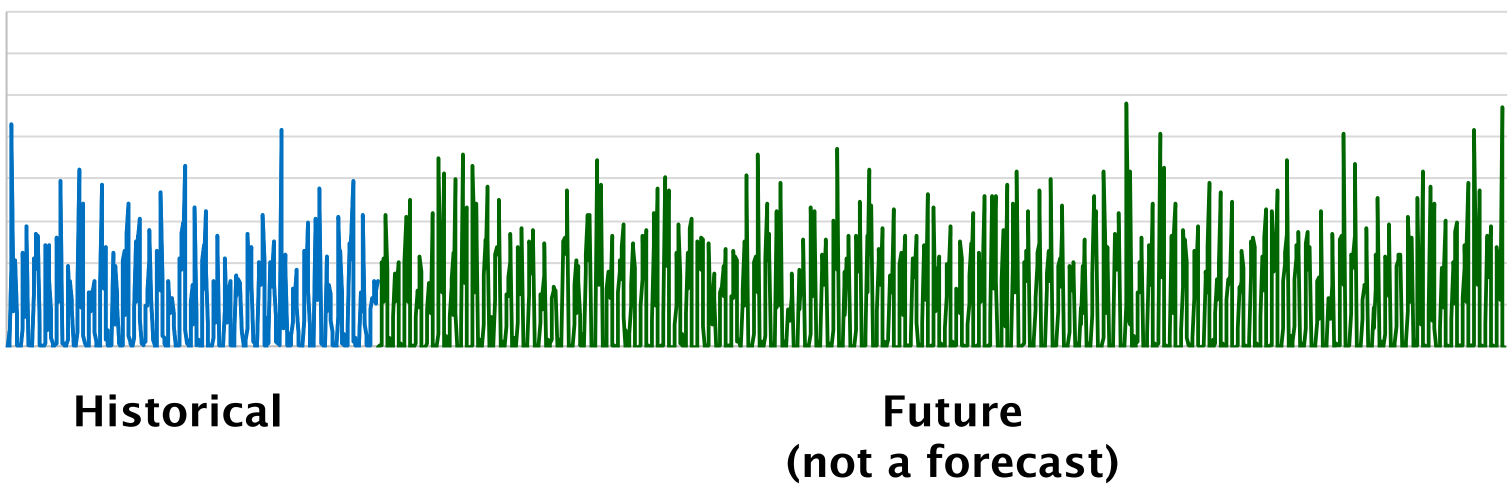


Hazard

Future weather time series

- ✓ *Future time series are generated stochastically from the historical information.*

- ✓ *The objective is <u>not</u> to forecast future weather conditions, but to generate feasible combinations of drought conditions, such as low precipitation and high temperature.*



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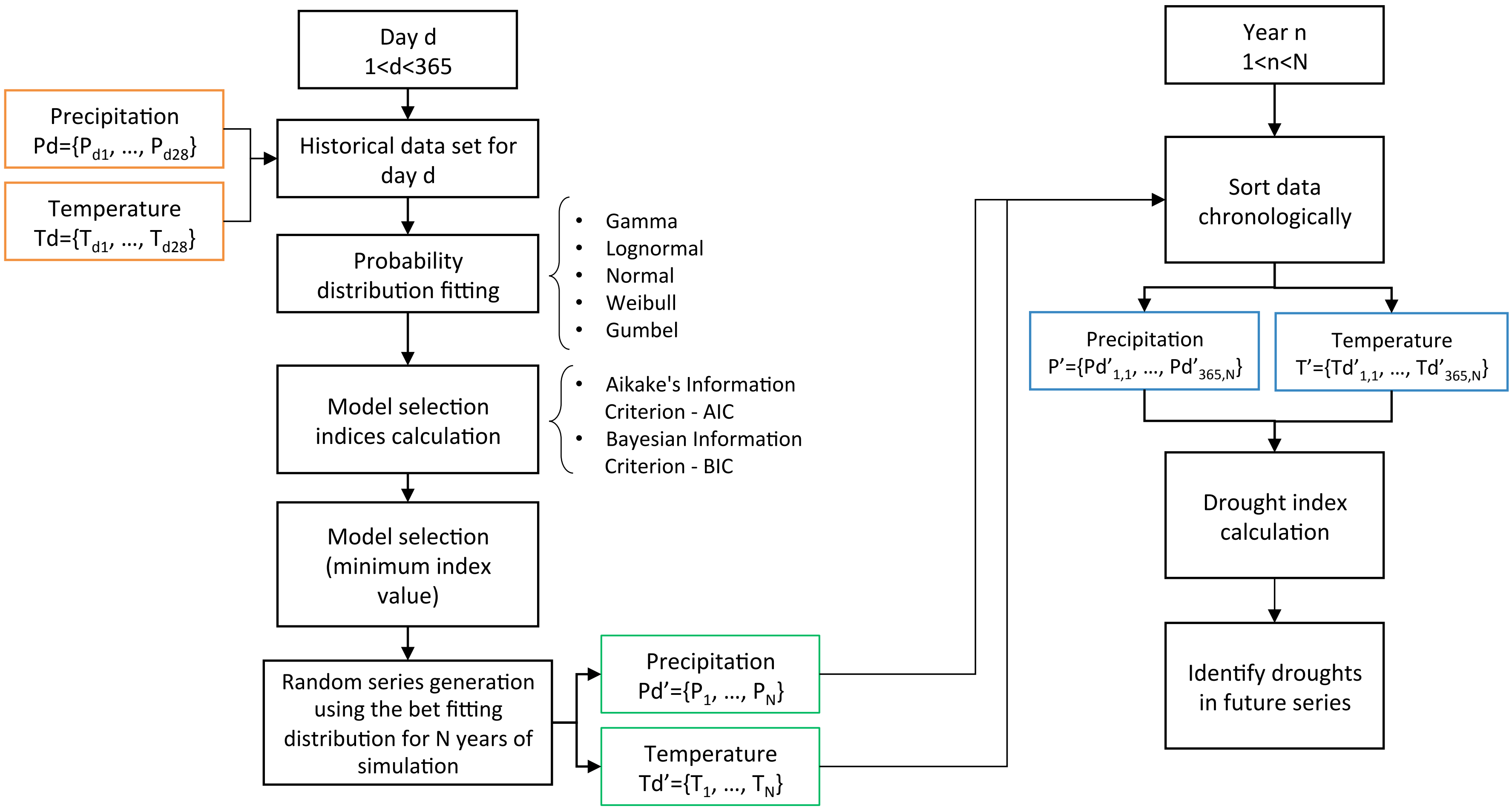
Hazard

Future weather time series



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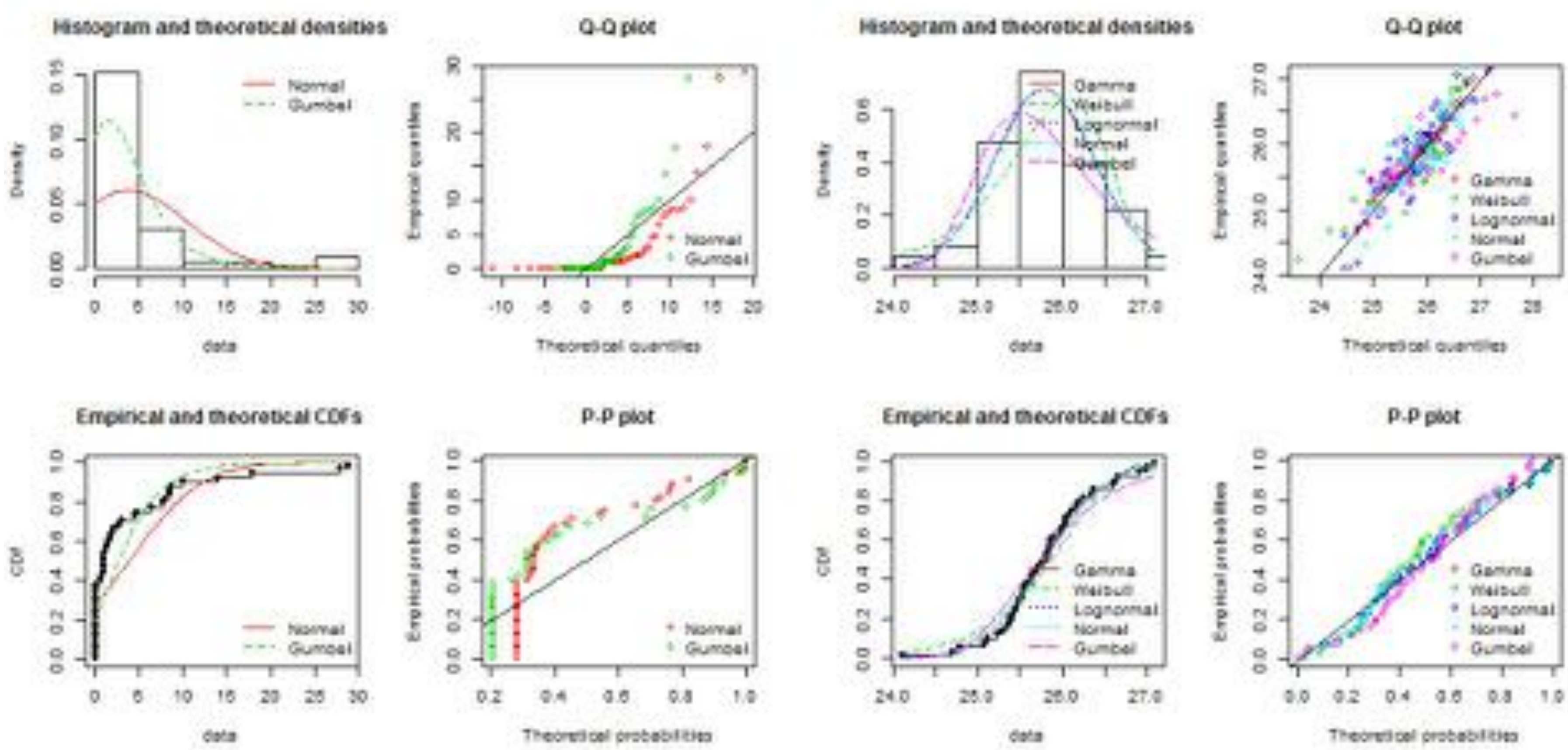
Hazard

Future weather time series

Probability distribution fitting

For example,

Precipitation, March 15th **Temperature, October 15th**



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Hazard

Future weather time series

Probability distribution of each weather variable, for each day

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Jan																															
Feb																															
Mar																															
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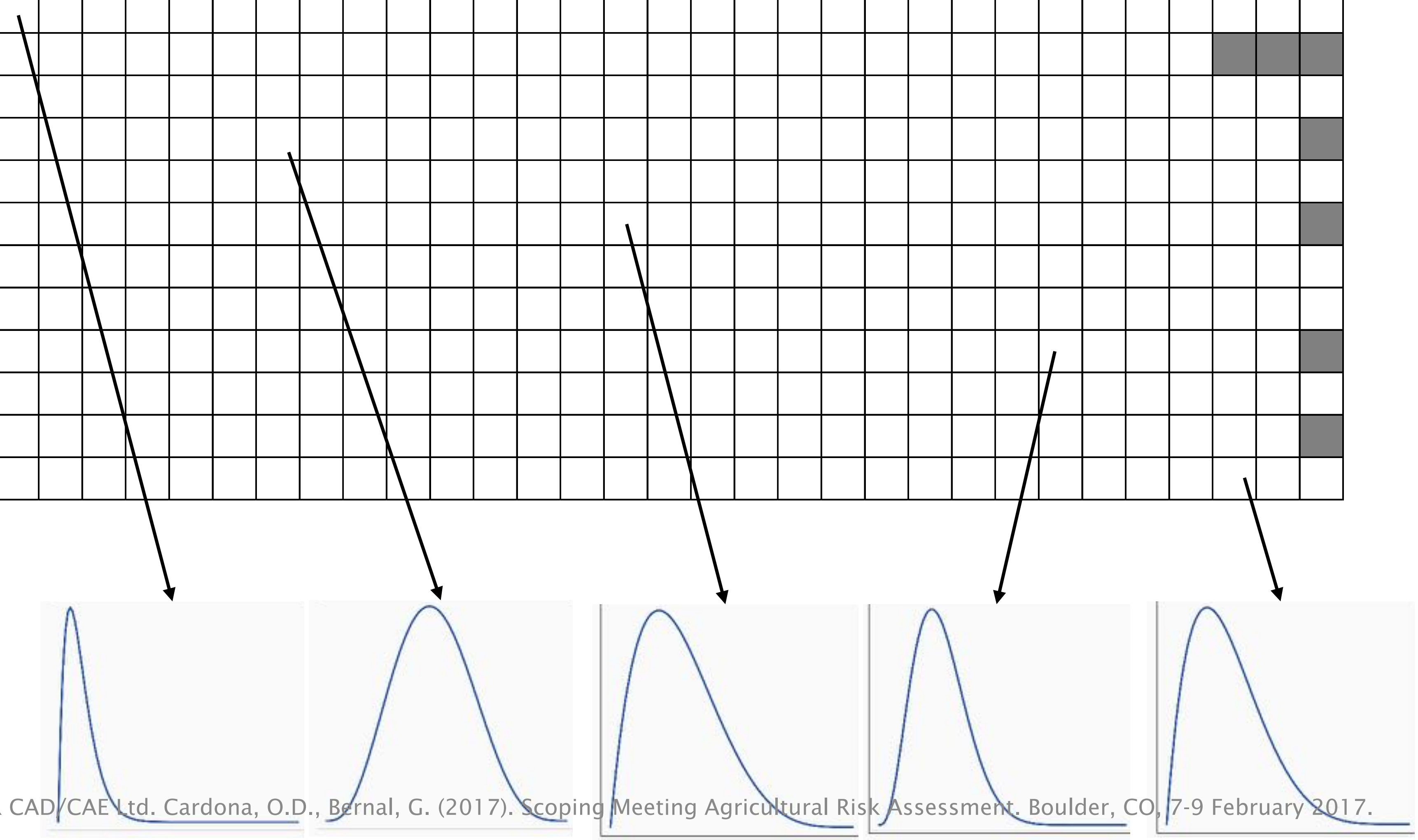

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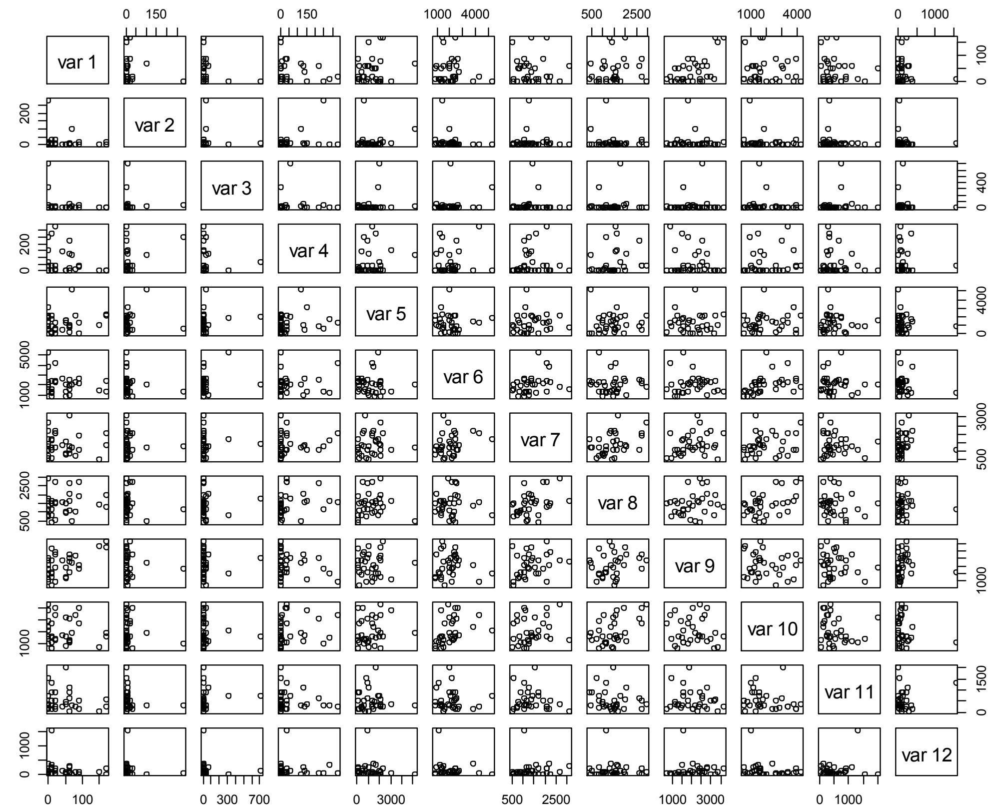
Hazard

Future weather time series

Correlation

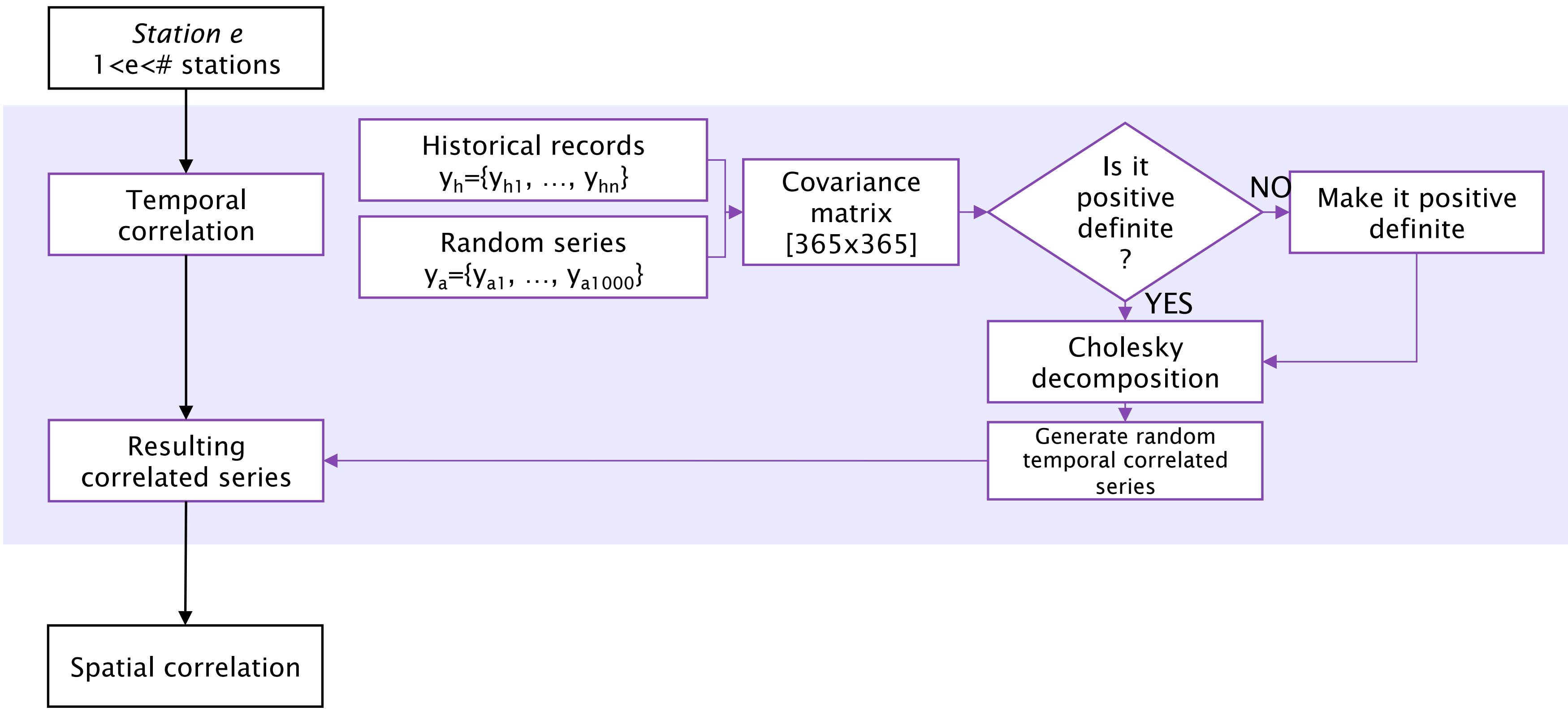
- ✓ *There is a certain amount of correlation, in both time and space, that cannot be neglected.*
- ✓ *Correlation is considered by means of a covariance matrix, between days of the year (for time correlation) and stations in the study area (for space correlation)*



Hazard

Temporal correlation of random series

Correlation



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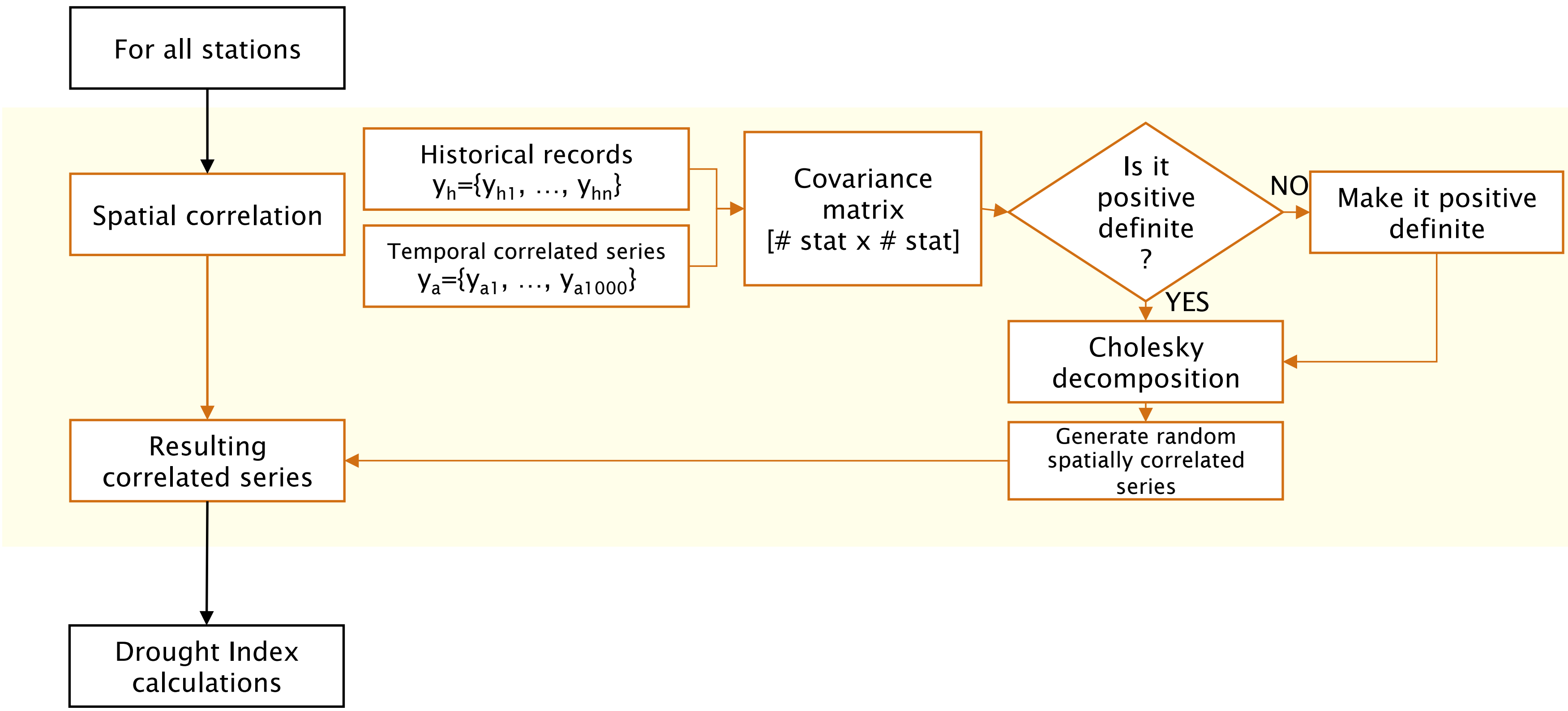
Hazard

Spatial correlation of random series

Correlation



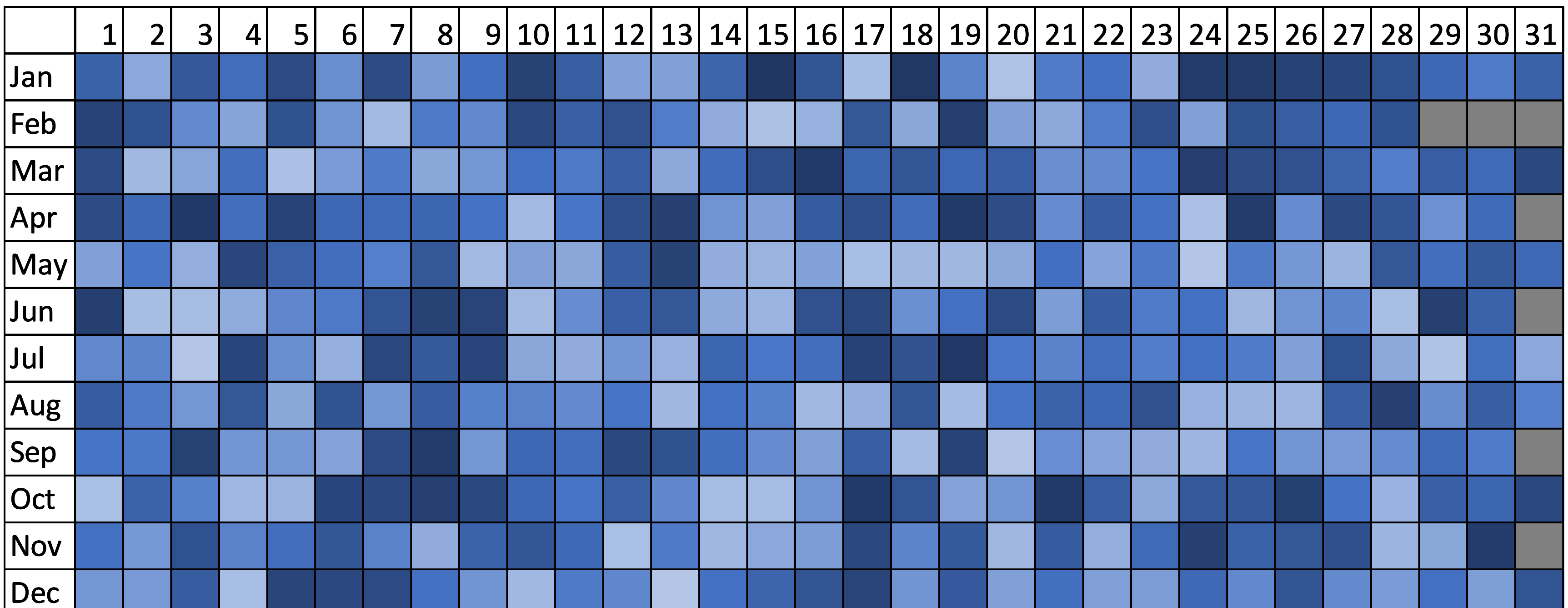
Hazard

Future weather time series

Simulations

- ✓ *Correlated random numbers are generated for each day of the year, for as may years as wanted.*

- ✓ *Each simulated year has different values of the weather parameters in each day, which follow the day-specific probability distribution and the temporal and spatial correlations.*



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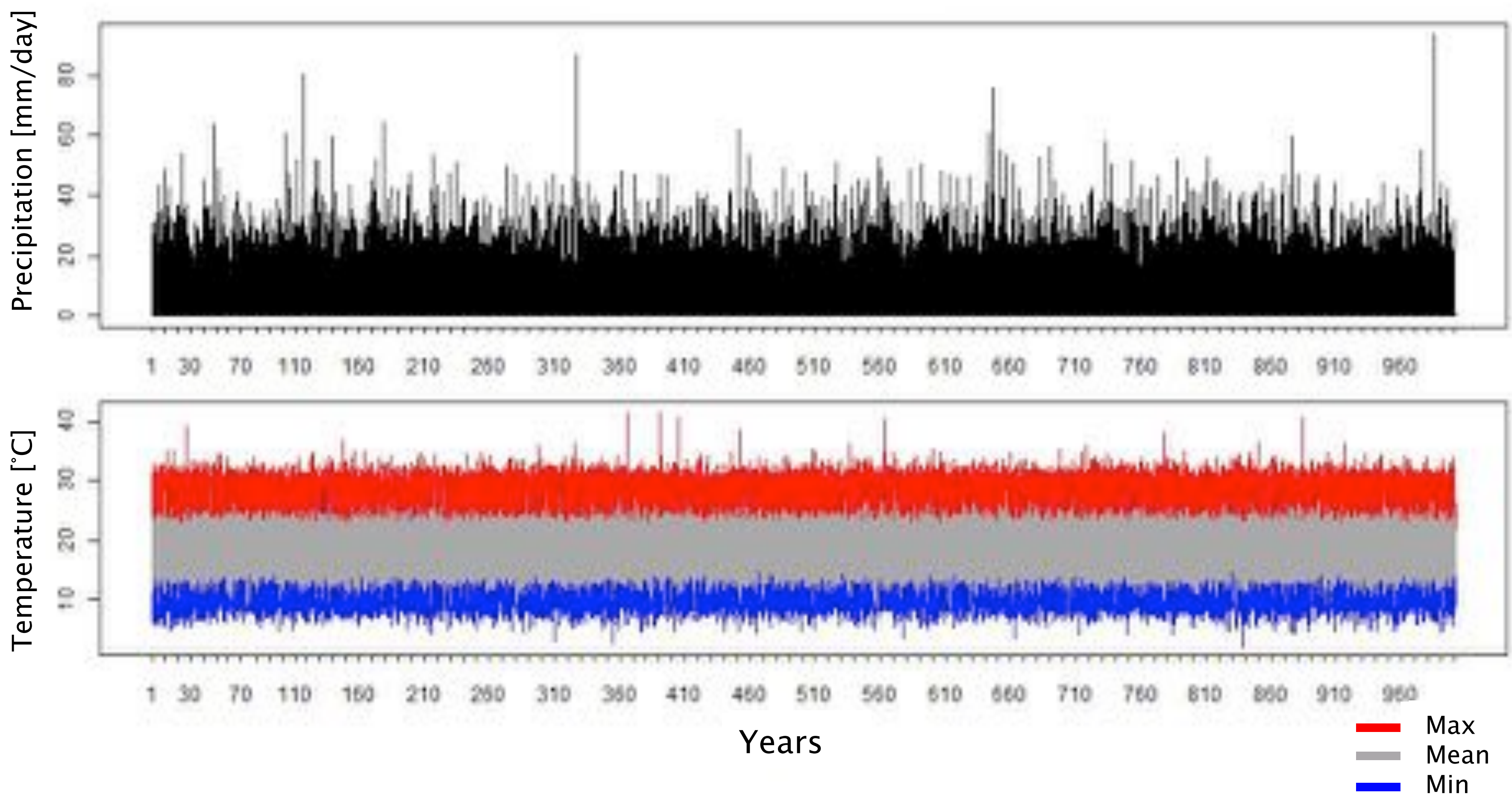
Hazard

Future weather time series

Simulations

This is repeated, for example, one thousand times.



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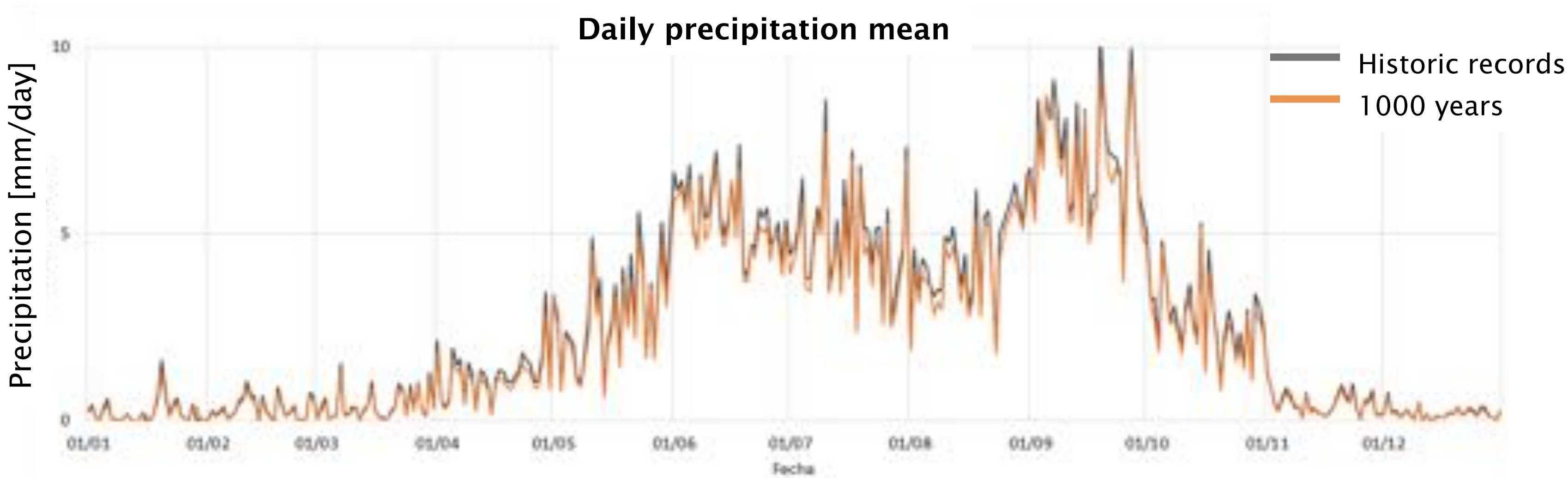
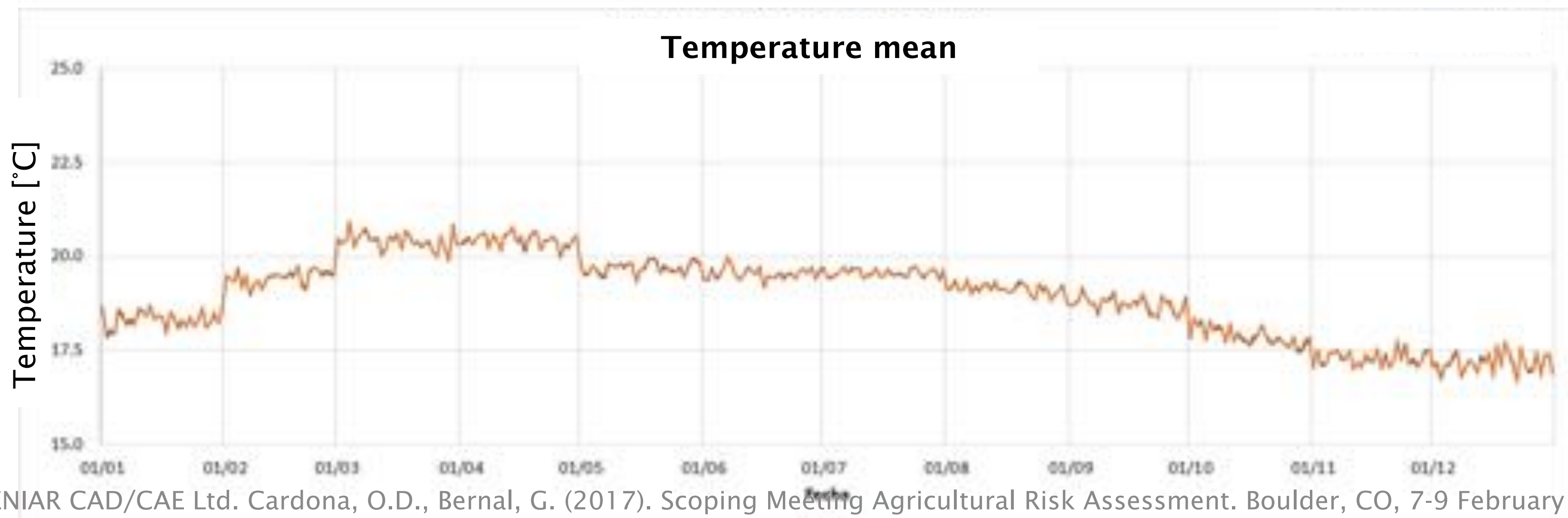
Hazard

Future weather time series

Simulations

Fitness check of multi-annual averages.





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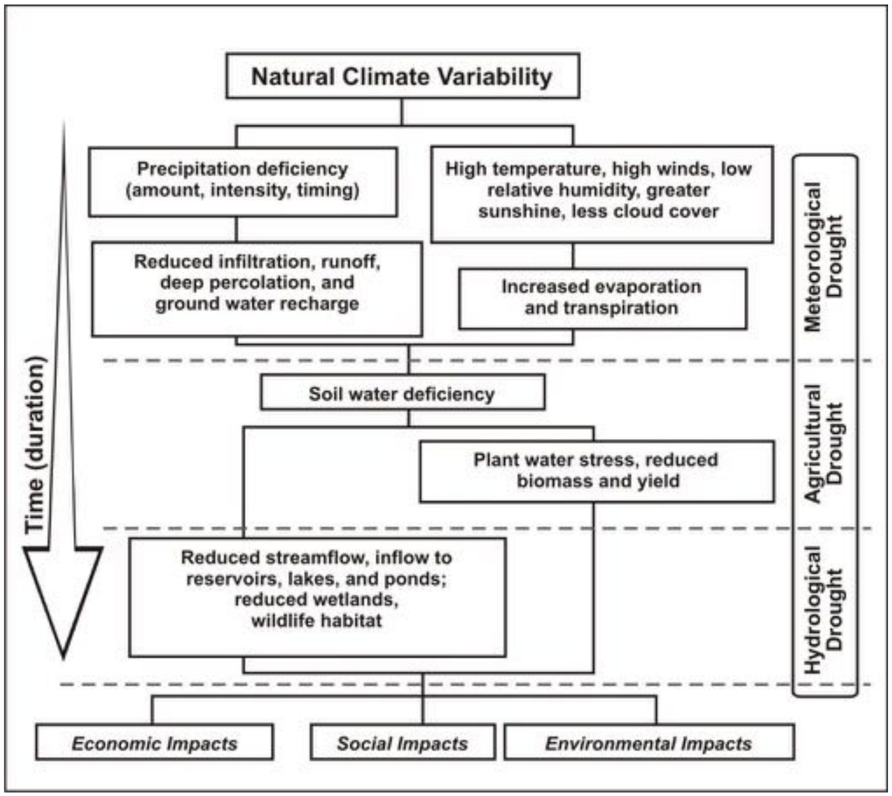
Drought Classification

Drought indices according to drought type



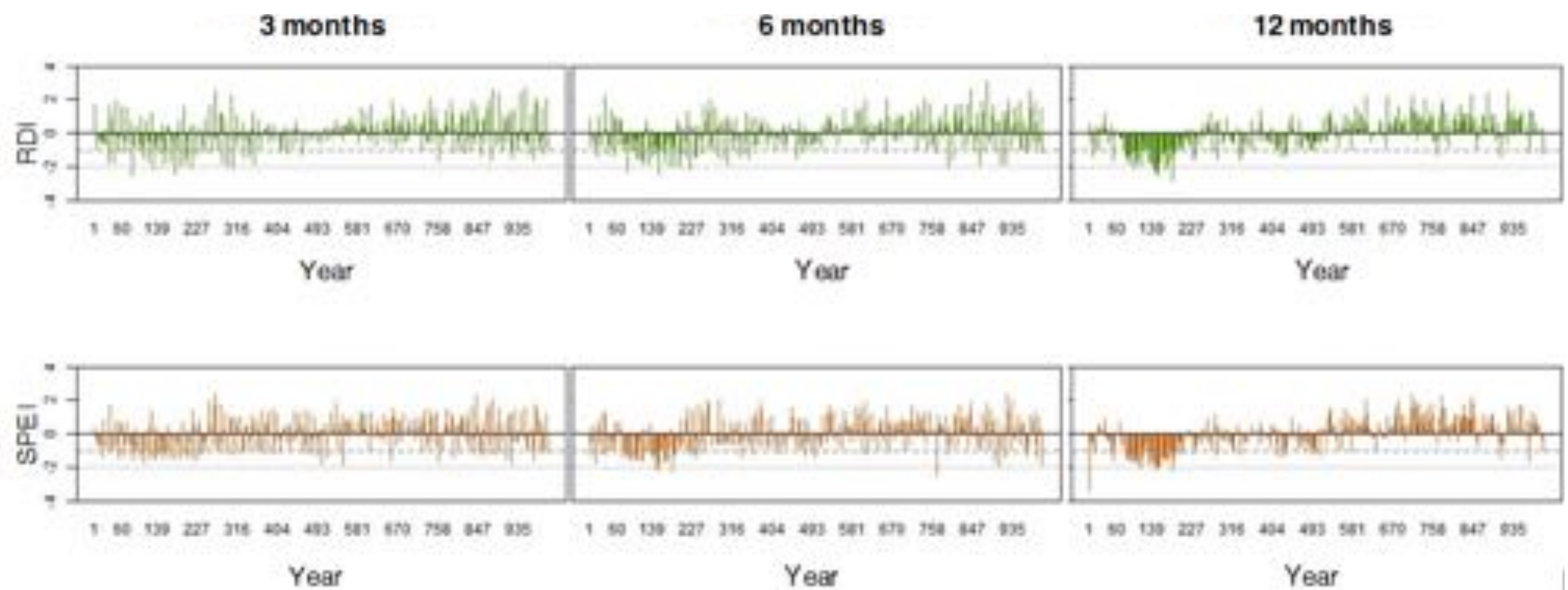
http://drought.unl.edu/

Precipitation deciles **SPI** Standardized Precipitation **EDI** Effective drought index	Precipitation
RDI Reconnaissance Drought Index **SPEI** Standardized Precipitation Evapotranspiration Index	Precipitation Temperature
PDSI Palmer Drought Severity Index	Precipitation, Temperature, Soil characteristics (porosity, moisture)
Surface Water Supply Index	Precipitation, snow, streamflow, water storage

Drought Indices

Time scale variation

Drought indicator series for 1000-years simulation



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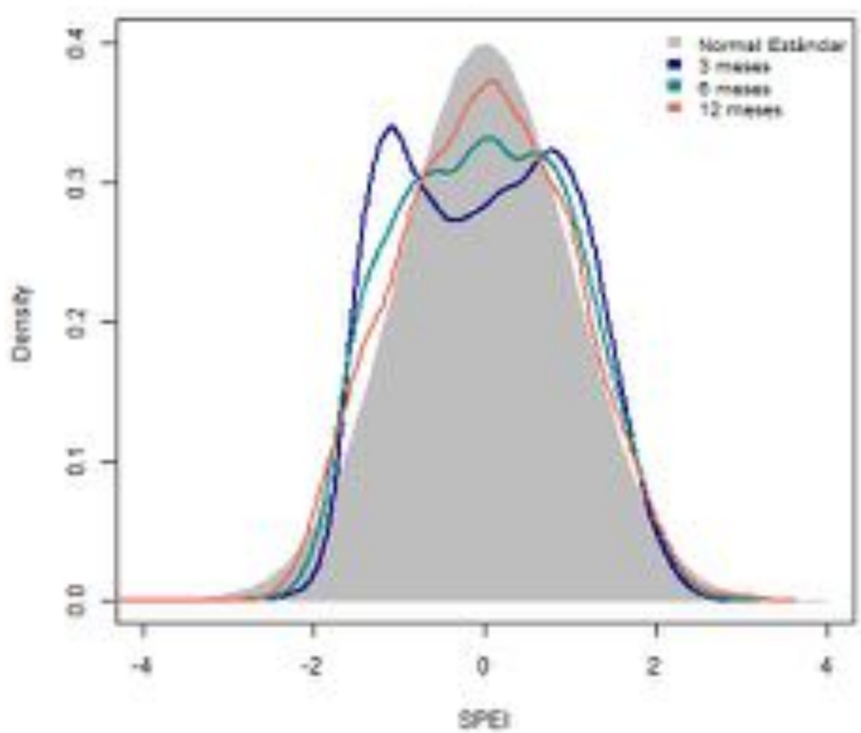
Drought Indices

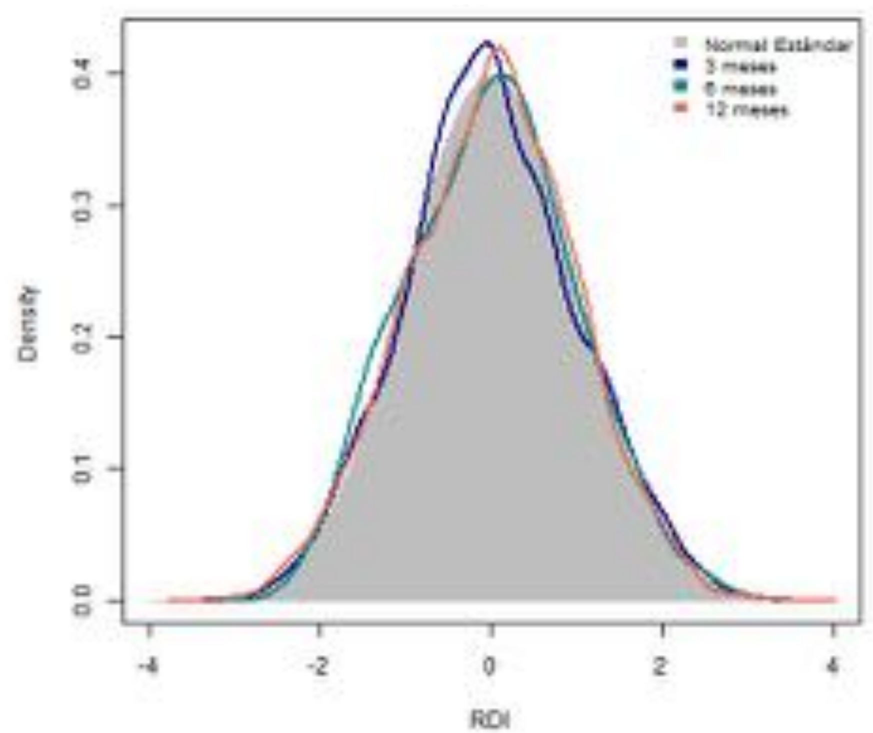
Select the best index according to local conditions

Index densities fit to a normal standard distribution

SPEI – 3, 6 and 12 months



RDI – 3, 6 and 12 months



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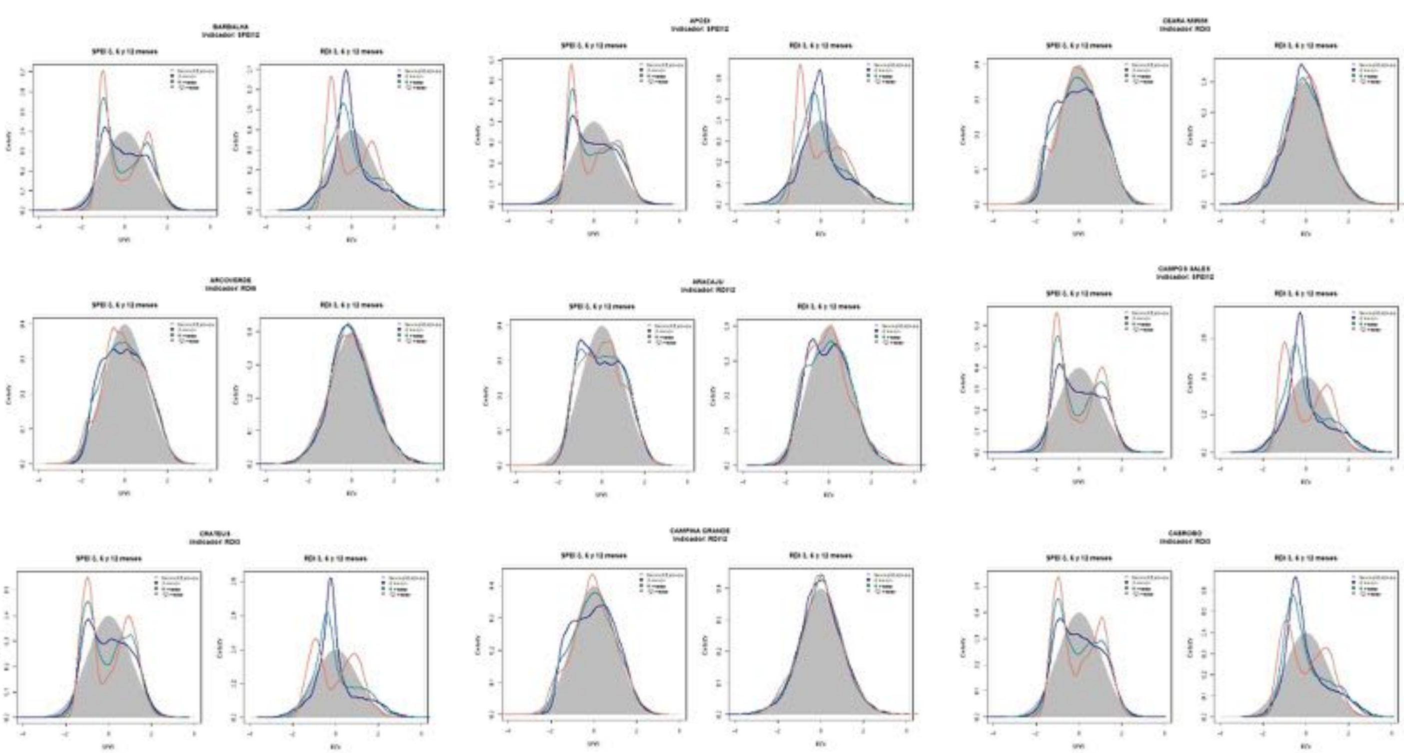
Drought Indices

Select the best index according to local conditions

Compare and select the index (and time scale) that better fits for most of the stations.



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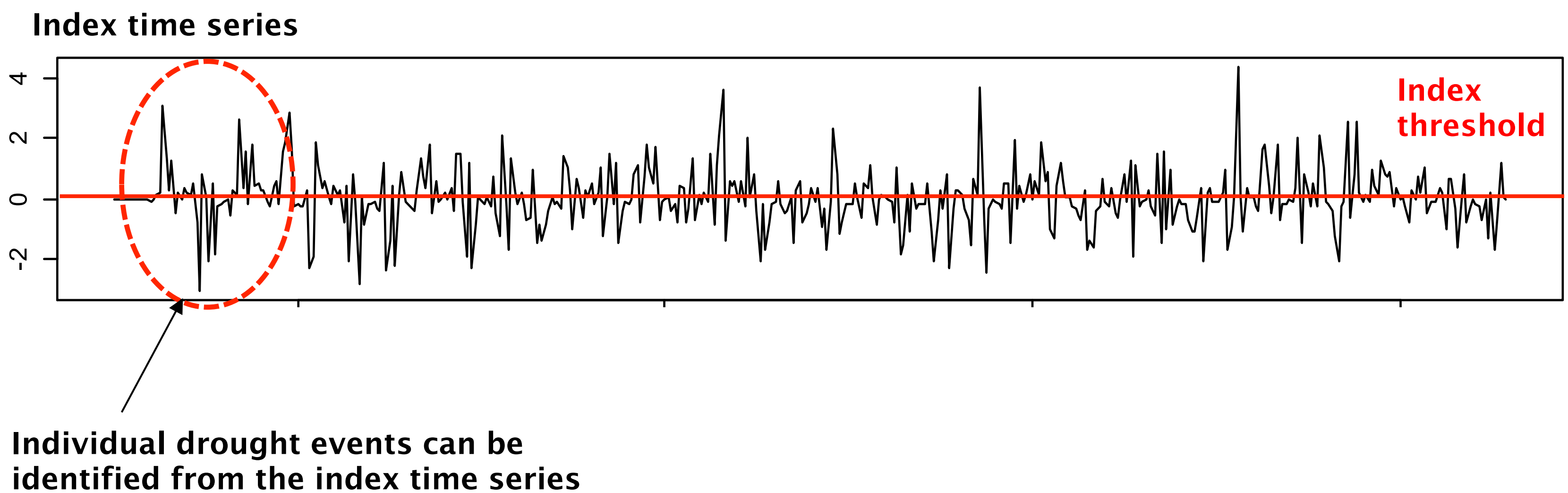
Drought Events

An index threshold must be defined to identify drought events.

Drought Classes	Index value
Non-drought	Index ≥ 0
Mild	-1 < Index<0
Moderate	-1.5 < Index ≤ -1
Sever/extreme	Index ≤ -1.5



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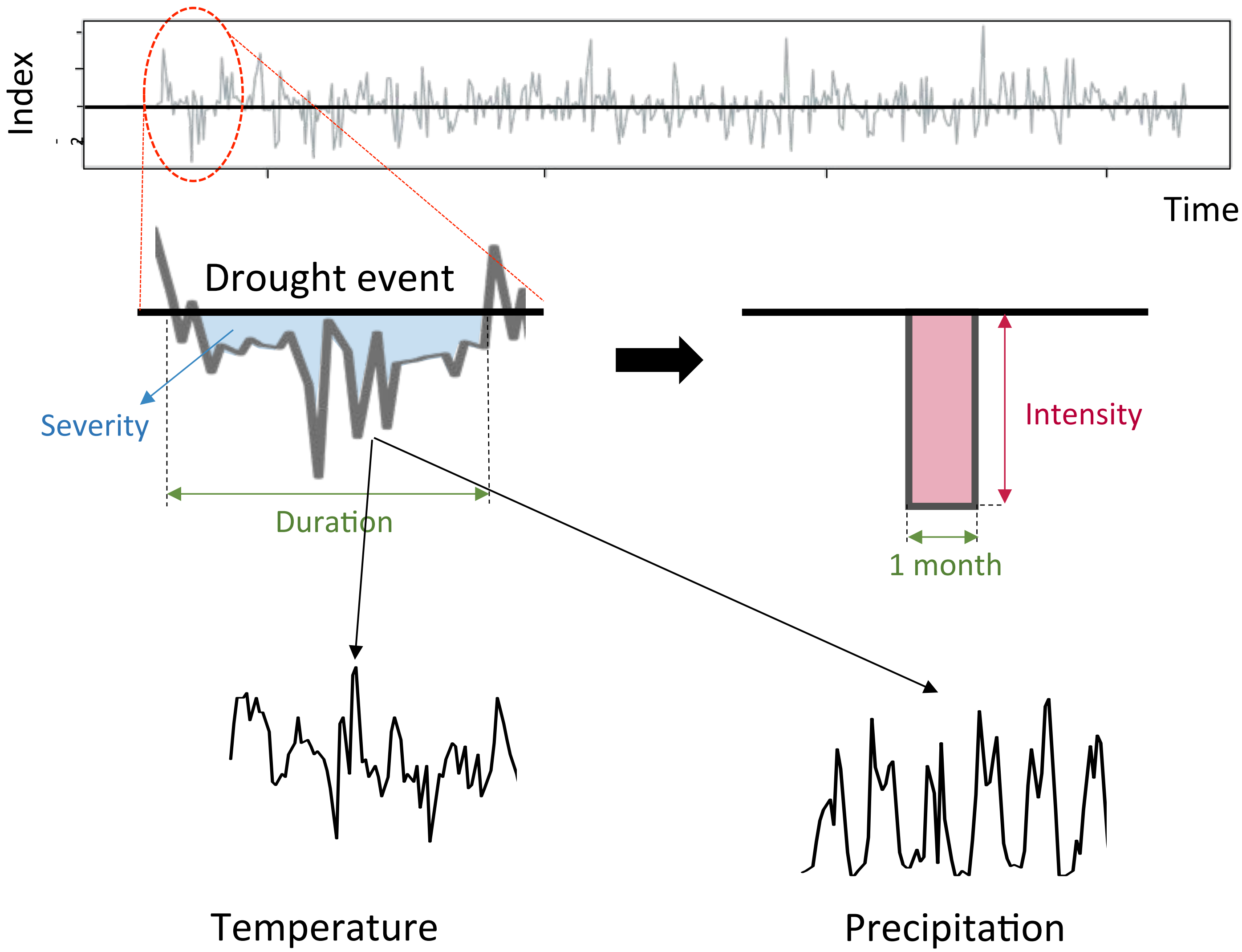
Drought Events

Each event is unique and has its own distribution in time



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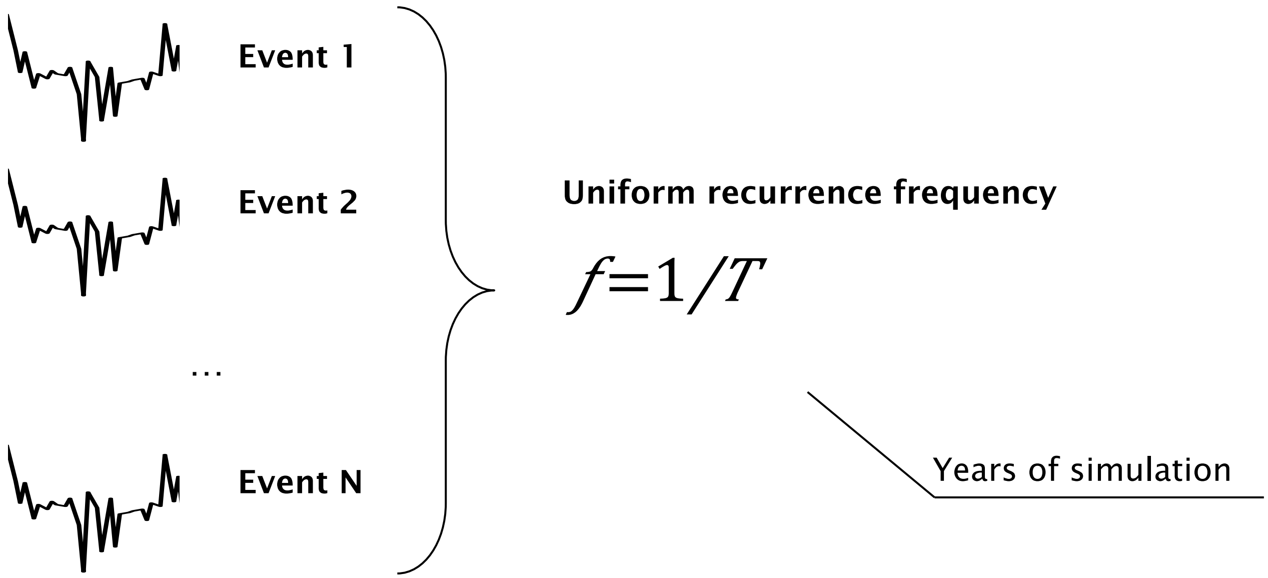
Drought Events

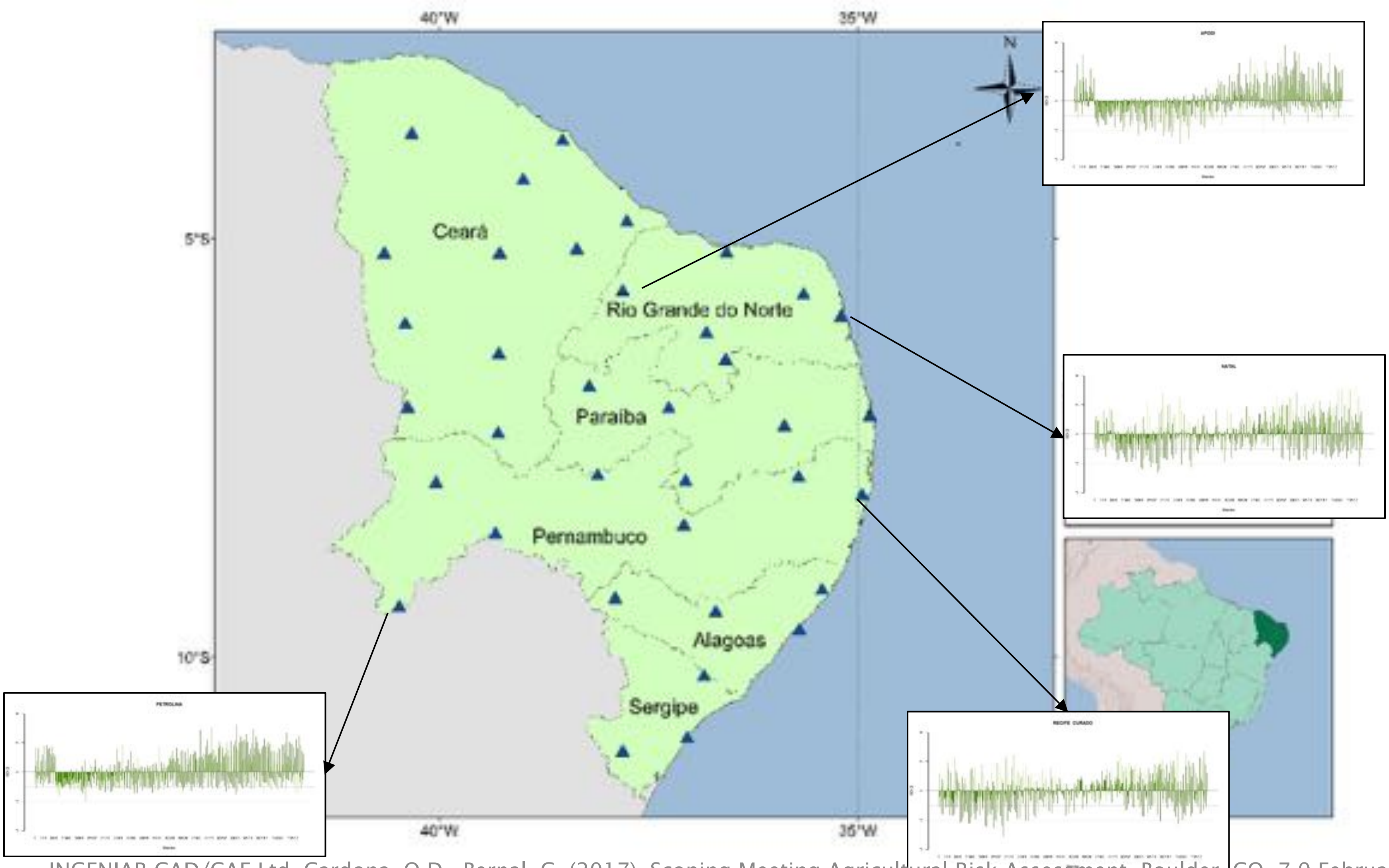
Frequency

All the drought events identified in the simulated series are selected to integrate the hazard model.



Drought Events

Drought index series are associated to particular stations.



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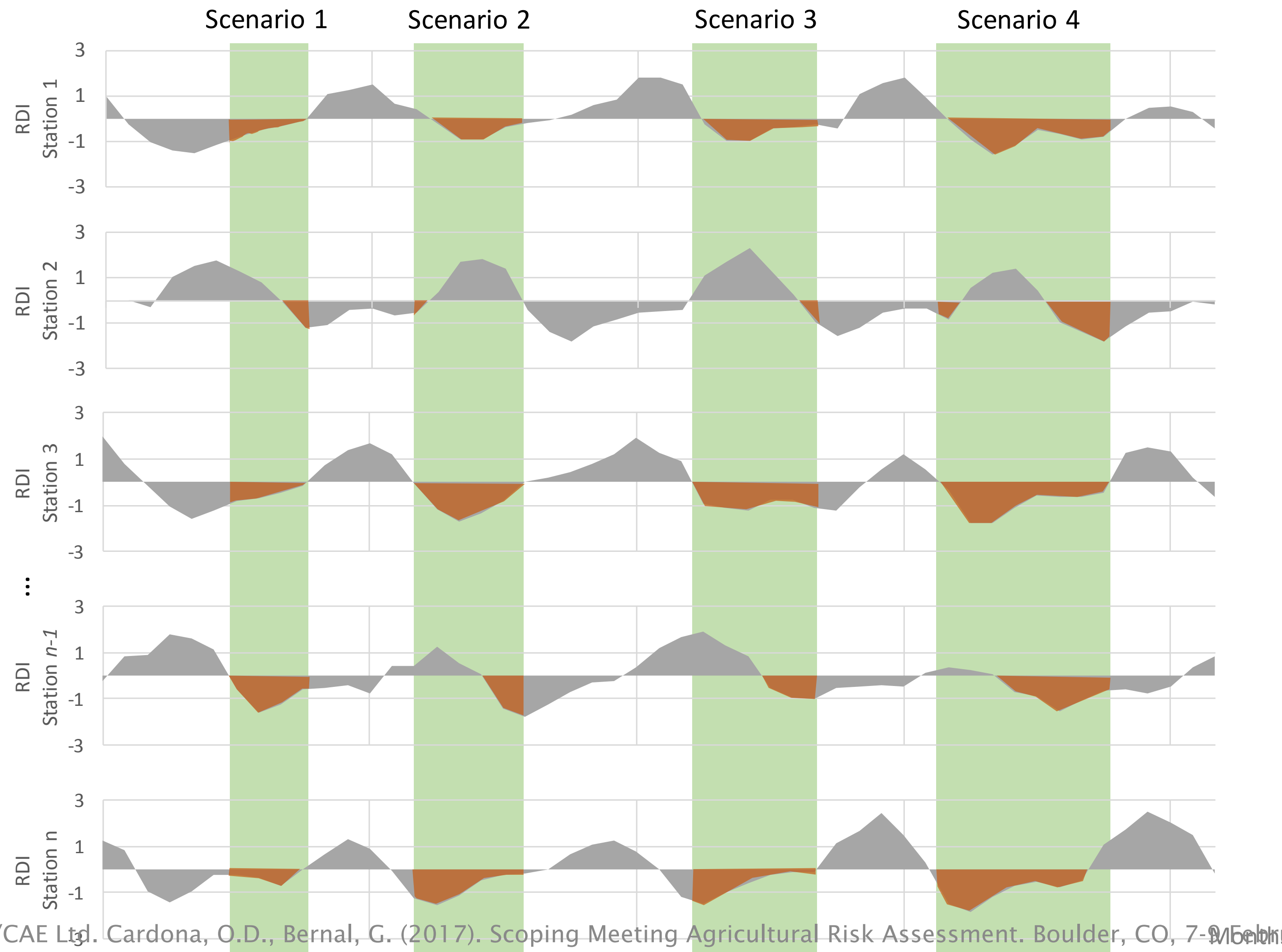
Drought Events

A regional event is identified when drought events are simultaneously identified in a substantial number of stations.



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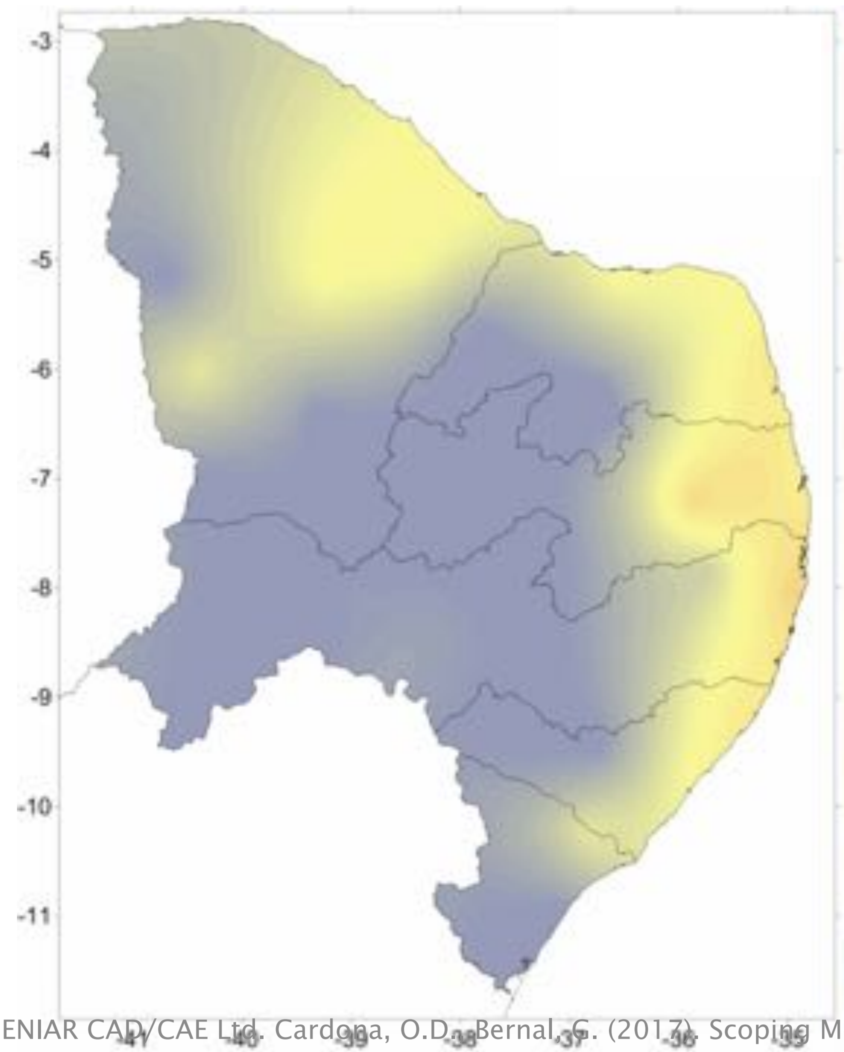
Drought Hazard

Collection of scenarios

Hazard is represented as a set of stochastic scenarios.



These scenarios (events) are assumed to be:

- ✓ *Mutually exclusive*
- ✓ *Collectively exhaustive*

They allow probabilistic representation:

- ✓ *Occurrence frequency (temporal probability)*
- ✓ *Gridded statistical moments (spatial probability)*
- ✓ *Time series, at any location, of weather variables (precipitation and temperature)*

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Drought Hazard

Hazard integration

Intensity exceedance rate

Exceedance probability given the occurrence of an event

$$v(a) = \sum_{i=1}^{i=N_E} \Pr(A > a \mid E_i) \cdot F_{E_i}$$

Intensity measure

Occurrence frequency

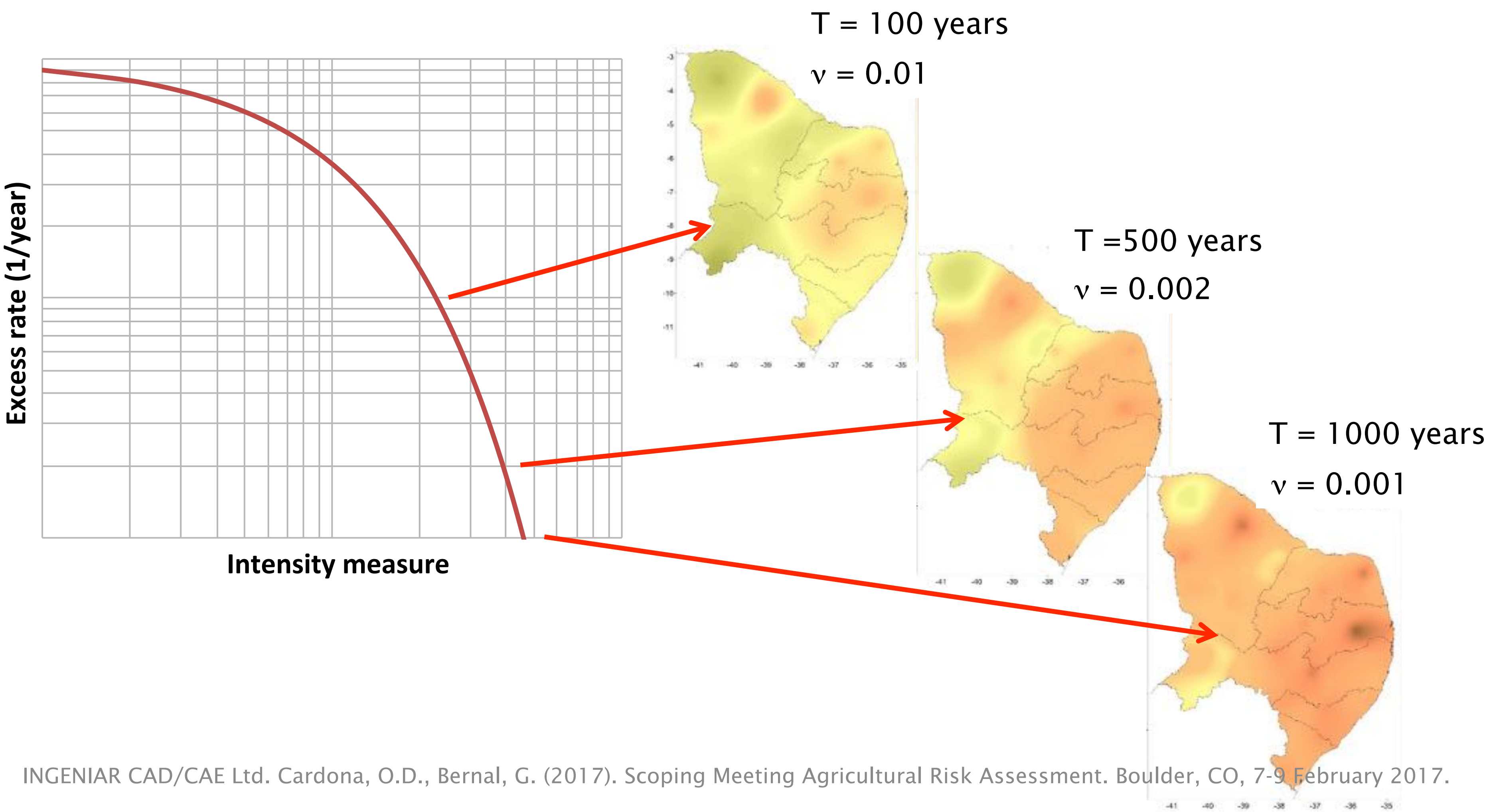
Sum for all events

Drought Hazard

Hazard integration

Intensity excess curve at each grid node

Hazard maps for several return periods



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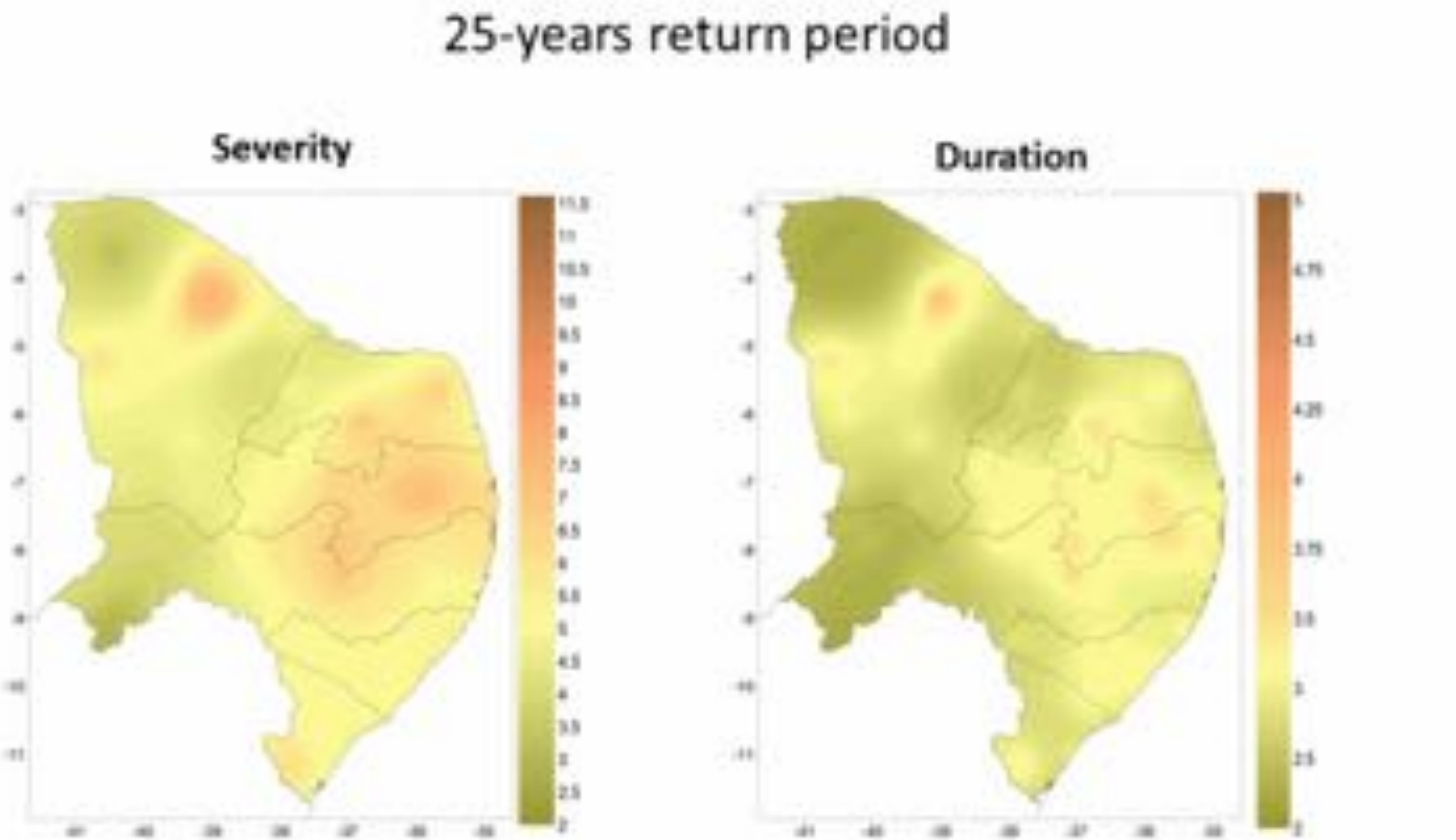
Drought Hazard

Hazard maps for any return period



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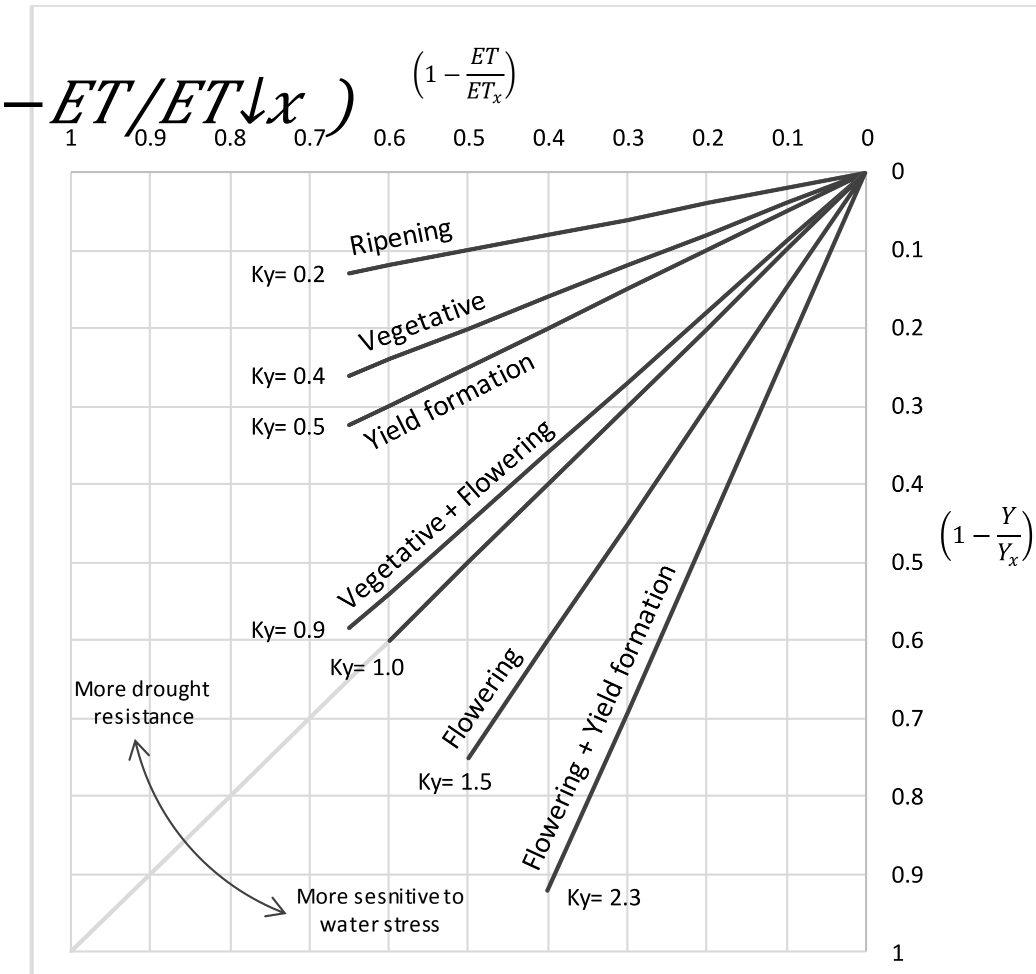
Vulnerability

Crop yield response to water

Traditional Approach

FAO: Irrigation and Drainage paper No. 33 Yield response to water (Doorenbos et. al. 1979)

$$(1-Y/Y_x) = K_y (1-ET/ET_x)$$



Linear water production functions for maize (Adapted from Figure 1 in Steduto et al., 2012, p. 8)

Extended Approach

Irrigation and Drainage Paper No. 66 Crop yield response to water (Steduto et al., 2012)

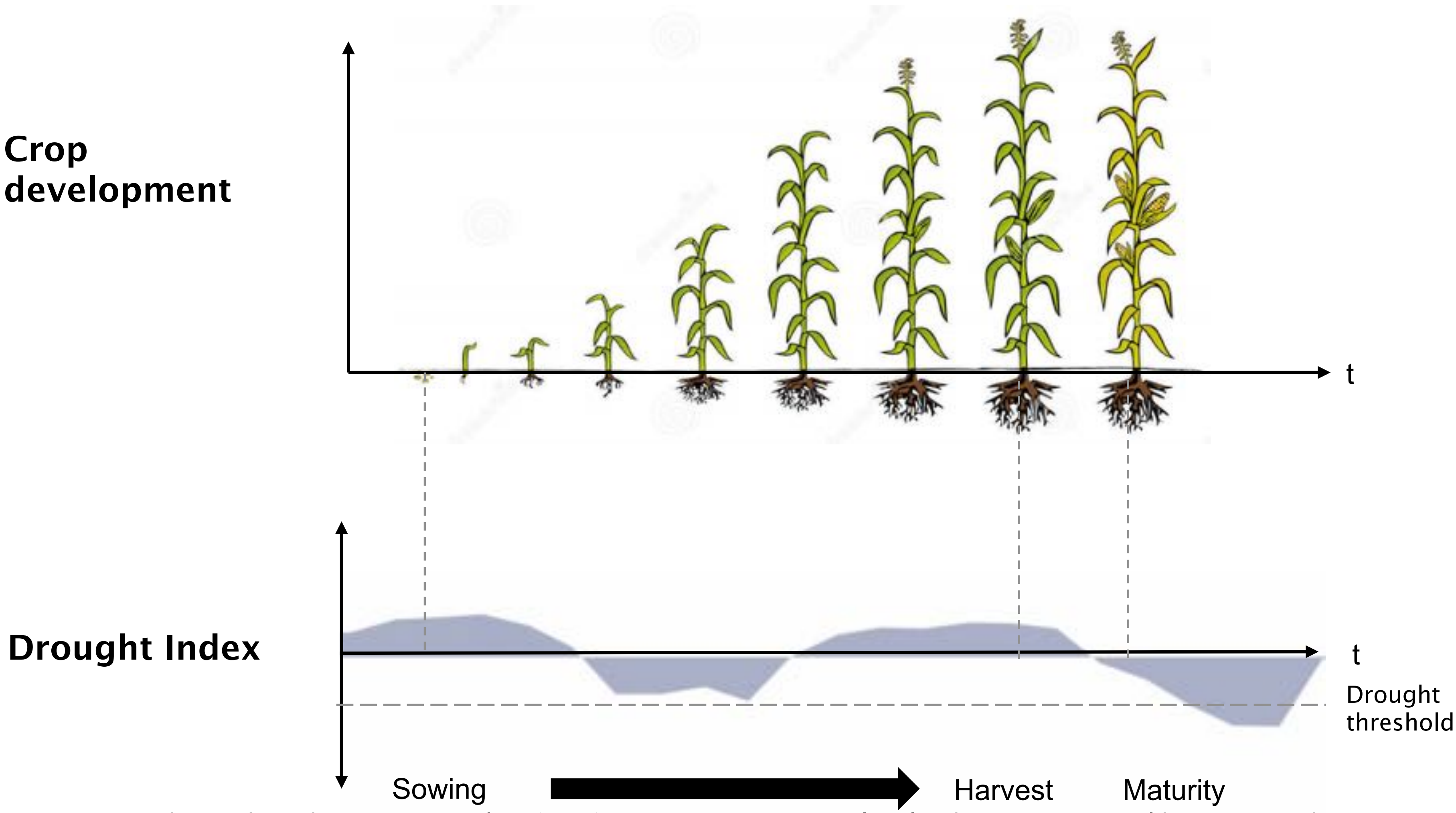
$$\left(1-\frac{Y}{Y_x}\right)=K_y\left(1-\frac{ET}{ET_x}\right)$$

$$ET=E*Tr$$

$$Y=HI*B \longrightarrow B=WP*\sum Tr$$

Crop Yield Response to Water

As crop seasonality is known, crop calendar is located in the same time-scale for each scenario.



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Vulnerability

5-steps process

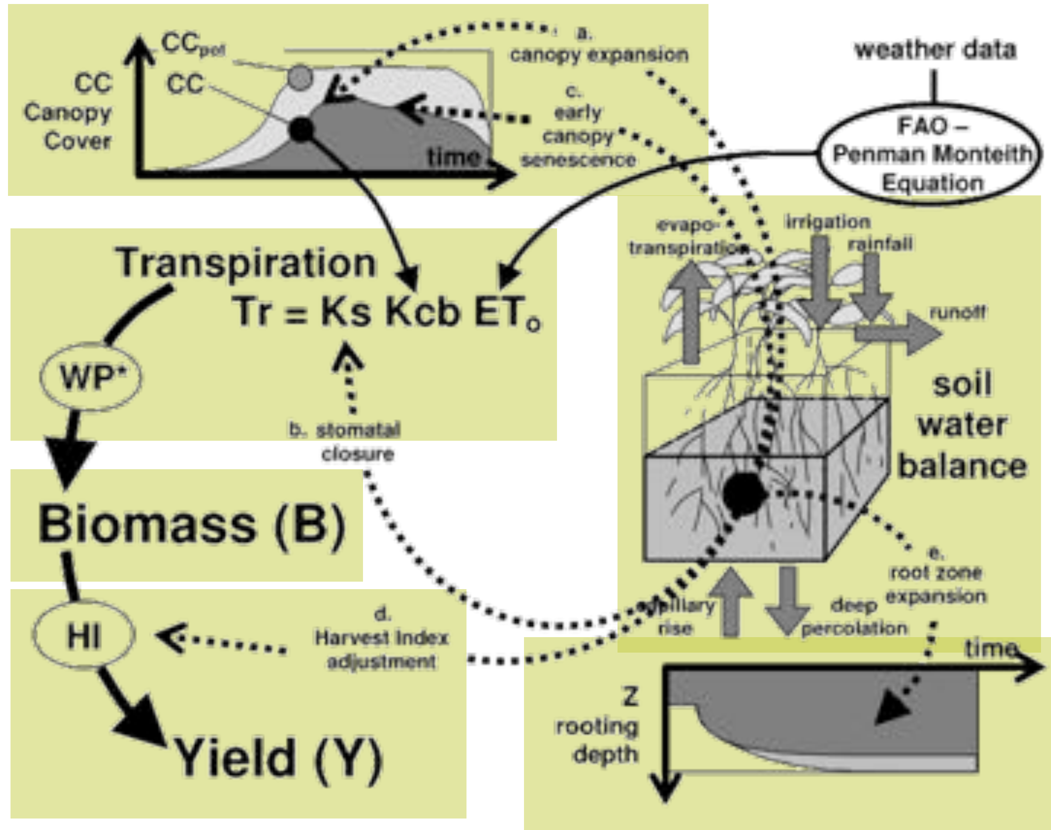
Soil water balance

Crop development

Crop transpiration

Biomass production

Yield (Y) from biomass (B)



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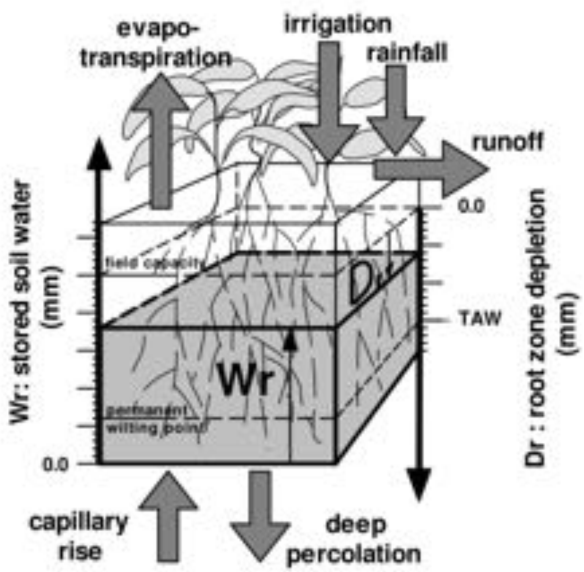
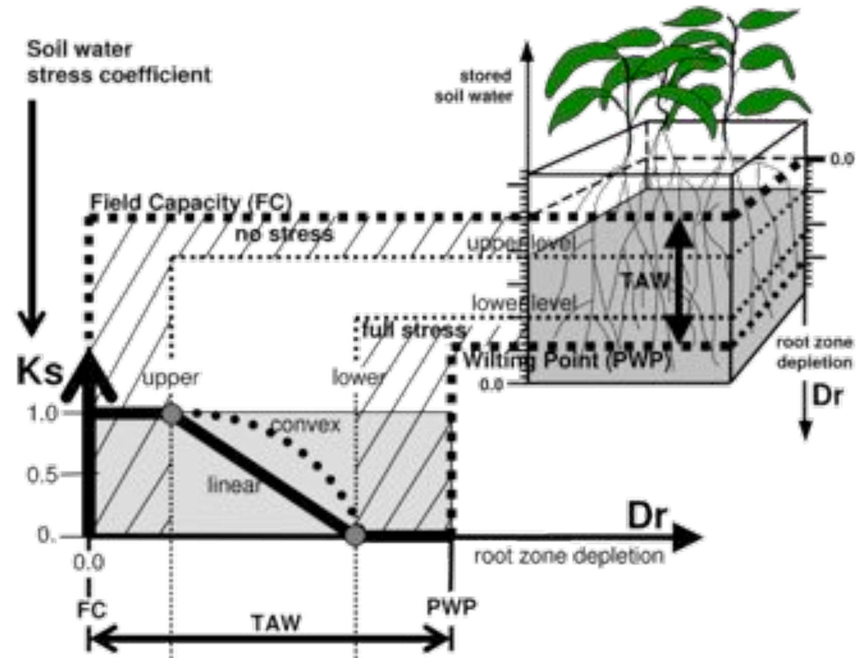
Yield Response to Water

1. Soil water balance in root zone





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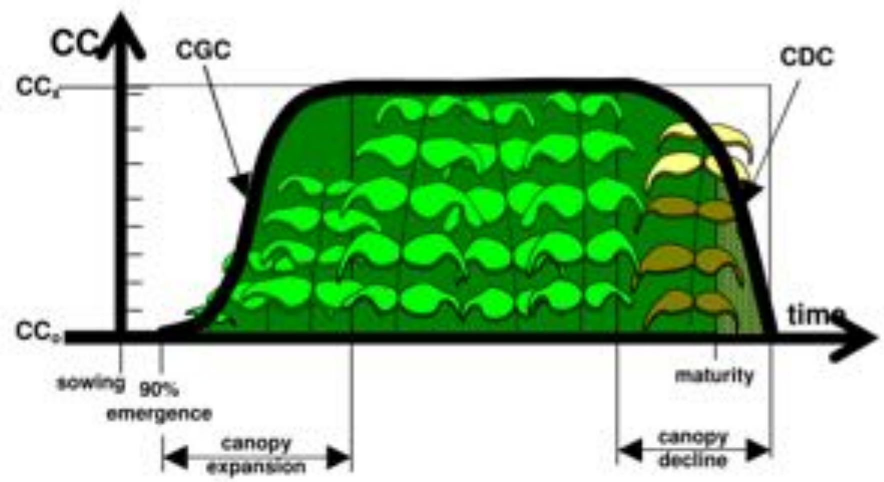
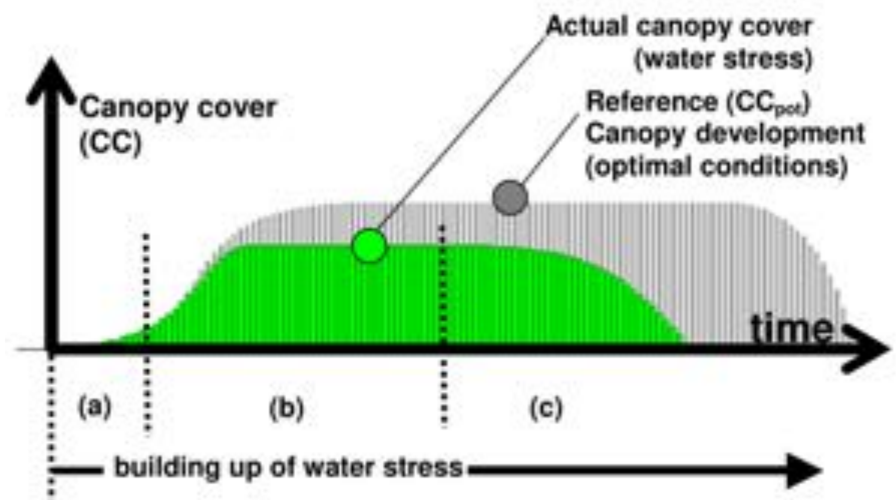
Yield Response to Water

2. Crop development





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Yield Response to Water

3. Crop transpiration

$$Tr = Ks\,(Kc_{Tr,x}\; CC^{*})\; ETo$$

Evaporative demand of the atmosphere

Canopy cover development adjusted for microadvective effects

Crop specific transpiration parameter

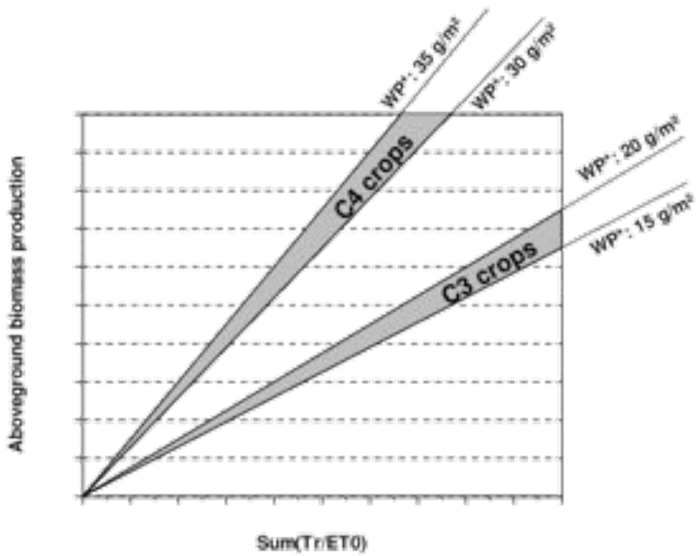
Stress (water or salinity) parameter

Yield Response to Water

4. Biomass production

$B = WP * \sum Tr$

Where, WP is the Water Production, which is the amount of biomass produced [kg] per area unit [m2] per water evapotranspired [m3]



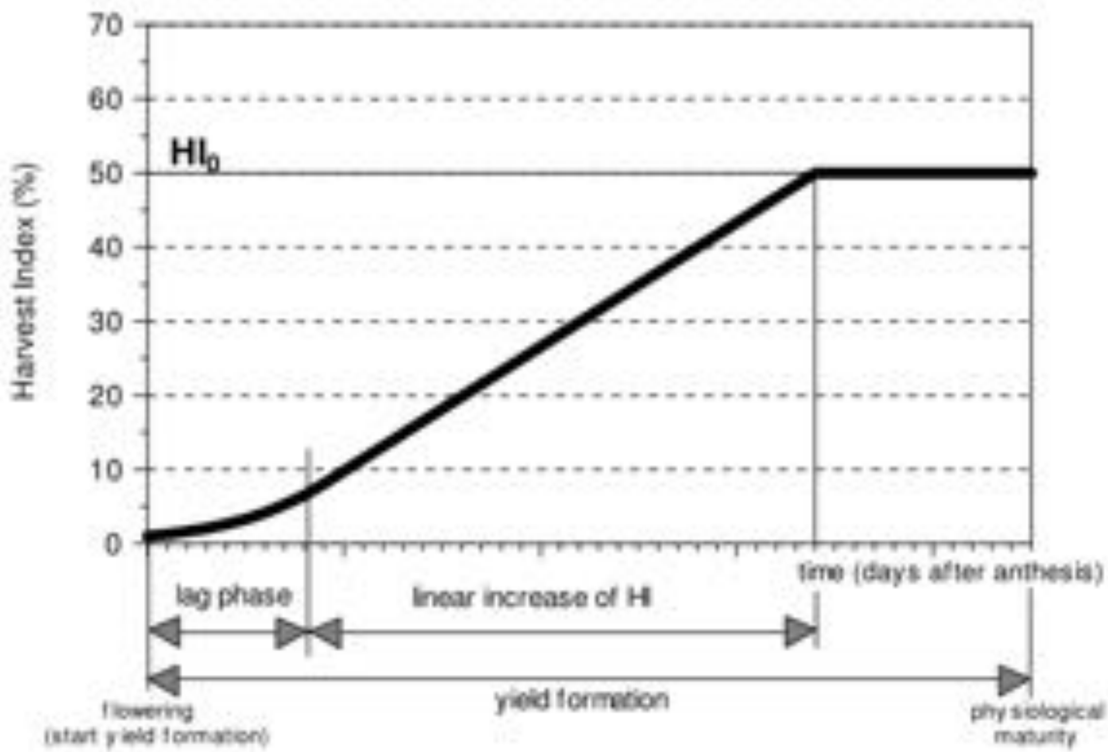
$$B = K_{sb}\, WP^* \sum_i Tr_i / ETo_i$$

Yield Response to Water

5. Yield (Y) from Biomass (B)

Potential Yield $Y_x = HI * B$

Actual Yield $Y = f_{HI} * HI_o * B$



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Crop Vulnerability

Inputs

Climate

Data from hazard modelling:
Air temperature, rainfall, ETo, CO_2

Crop characteristics

Phenology, canopy development, root deepening, seasonality

Soil profile

Soil horizons, soil surface, restrictive layers, capillary rise

Management

Modifiers: irrigation and fertilizers

Outputs

Yield

- *Optimum yield production*
- *Yield production under water stress*

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Crop Vulnerability

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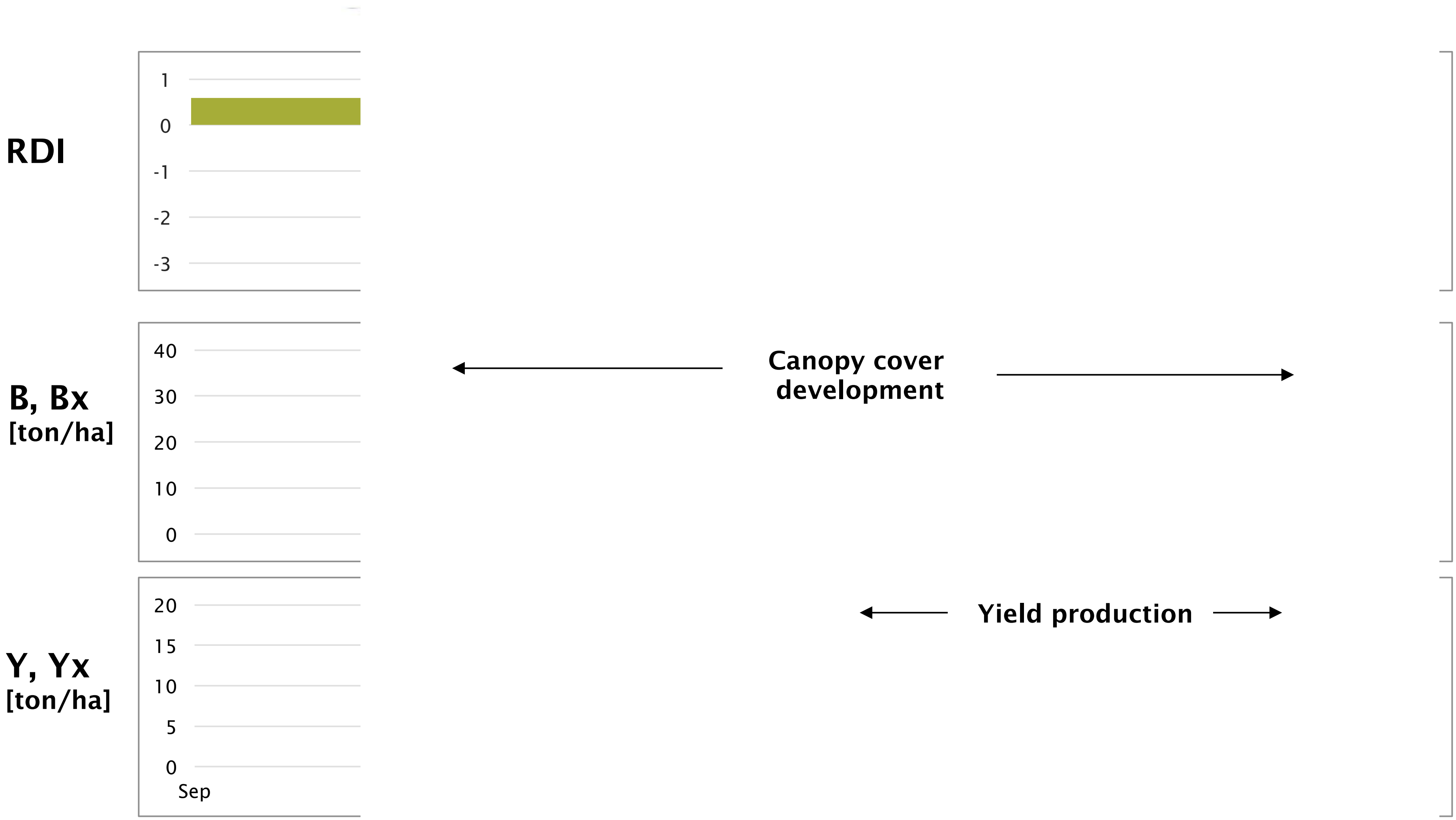
Crop Vulnerability



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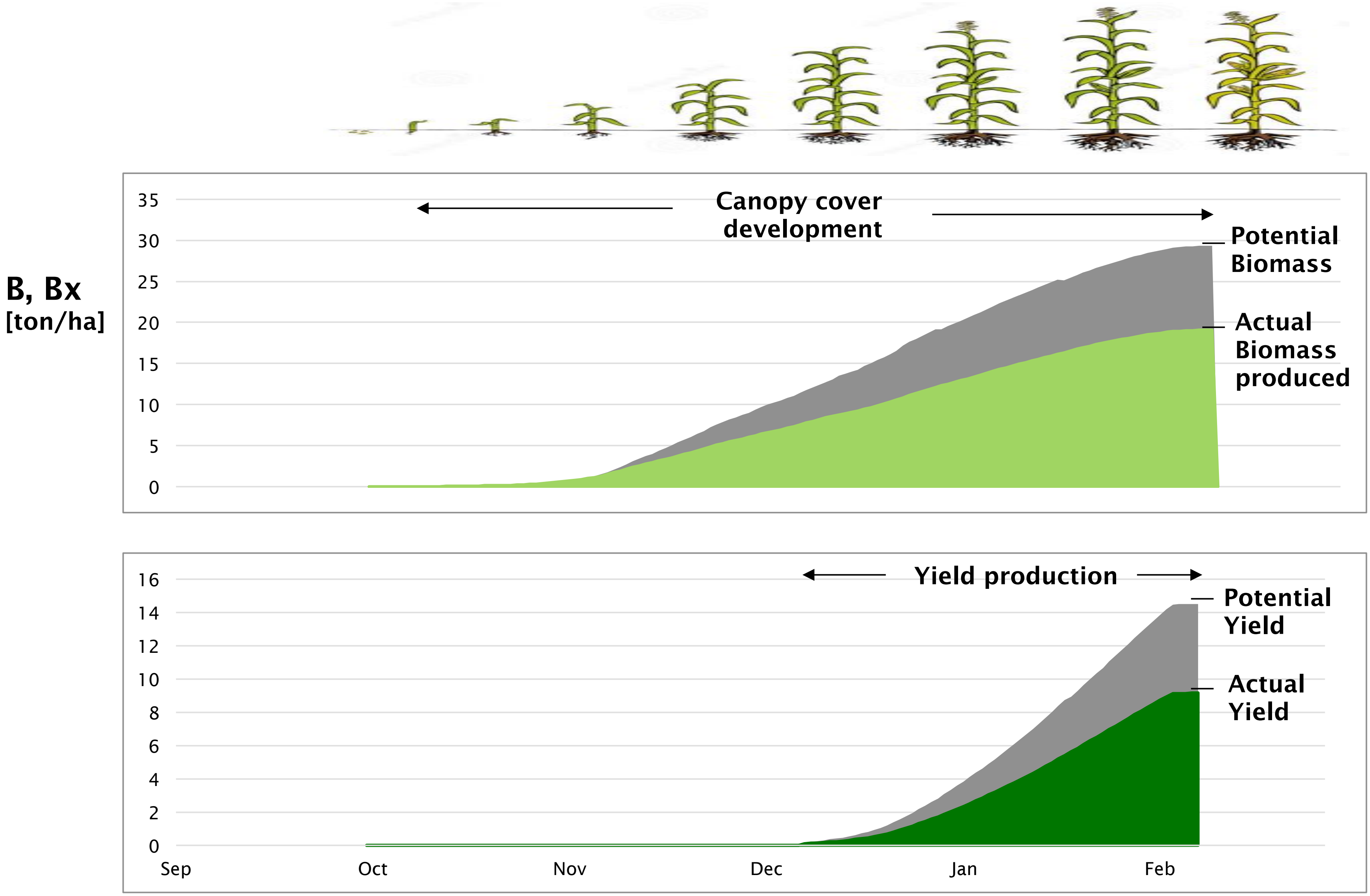
Crop Vulnerability



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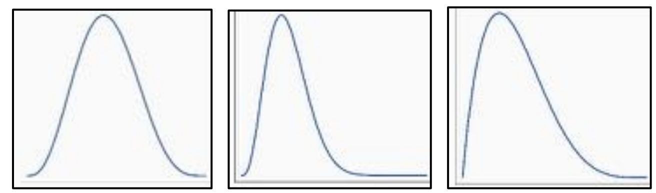
Crop Vulnerability

Simulations

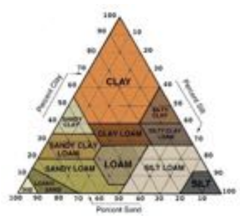
Uncertainty in input parameters is included from the avaliable information and expert criteria (likelihood)

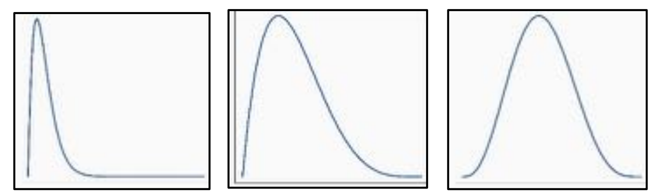
Inputs

Crop characteristics



Soil profile





Random variables

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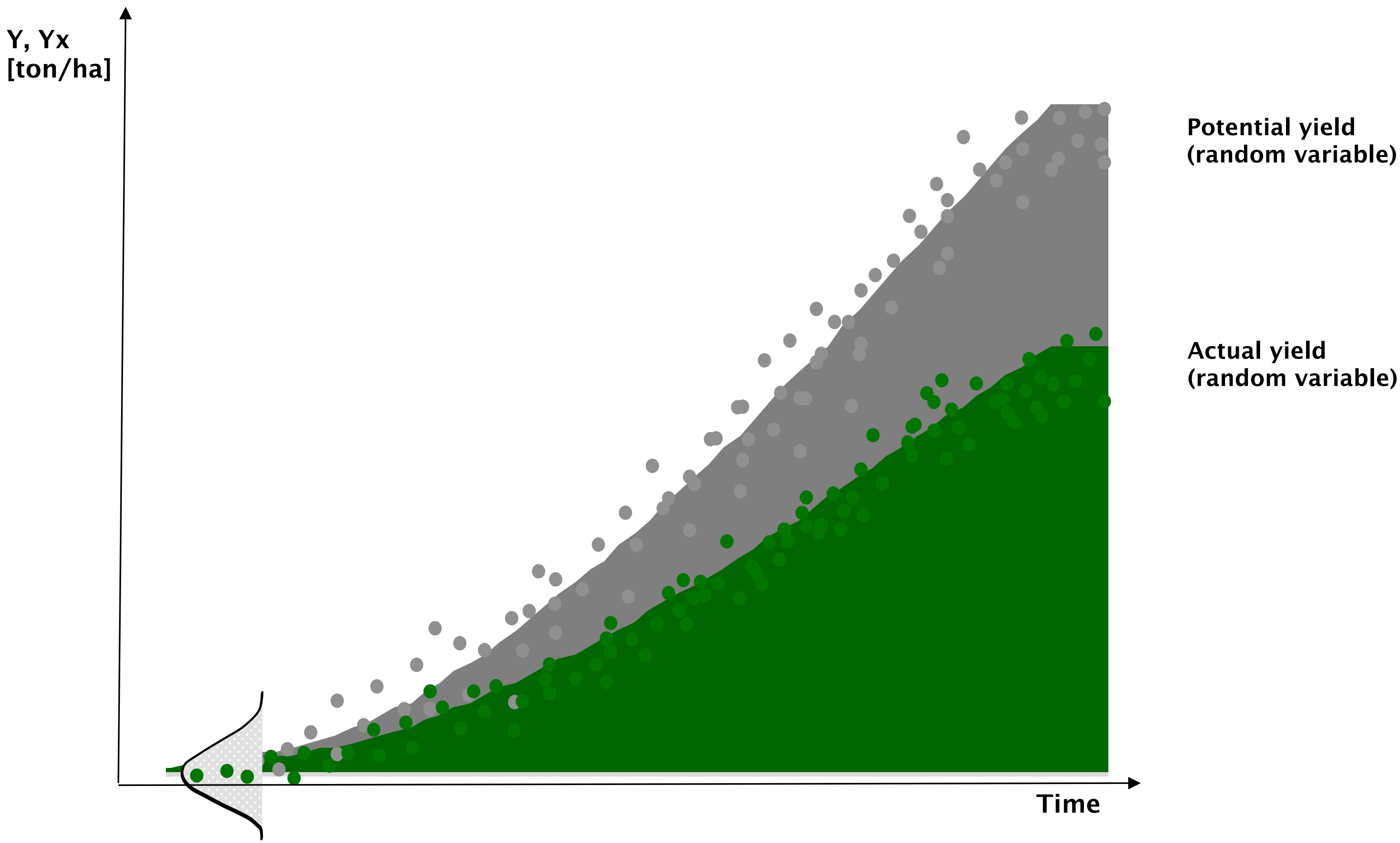
Crop Vulnerability

Simulations



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Exposure

Exposure

Inputs

Location		*Georeferenced data, area*
Crop characteristics		*Type and seasonality*
Crop valuation		*Production cost*

Outputs

Exposed elements database		*Geographical distribution*

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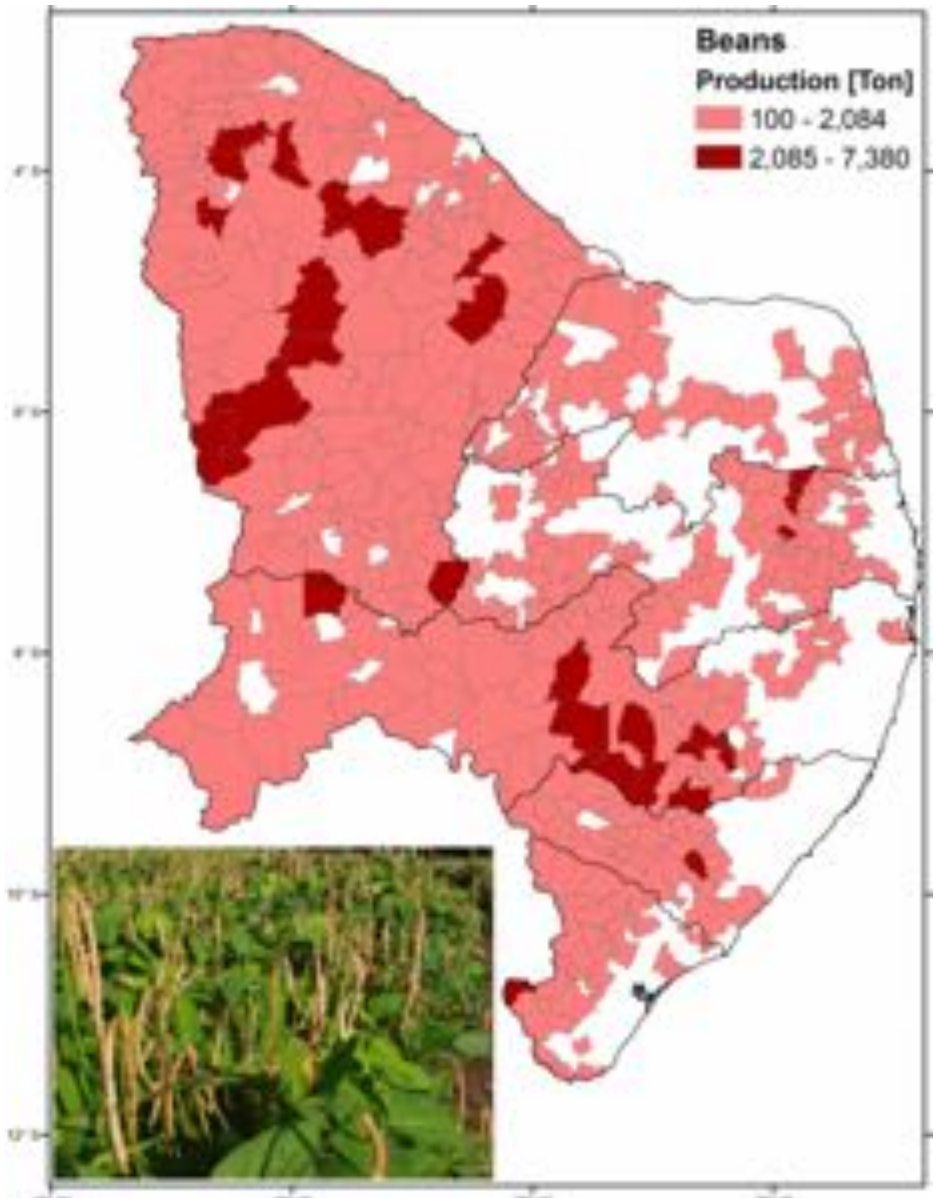
Exposure

Cultivated Area Units

- ✓ *Exposure is defined within Cultivated Area Units.*
- ✓ *Each unit is characterized by the following properties:*
  - *Geographical location*
  - *Type of crops produced*
  - *Crops production cost*
  - *Participation of each crop in the total production*



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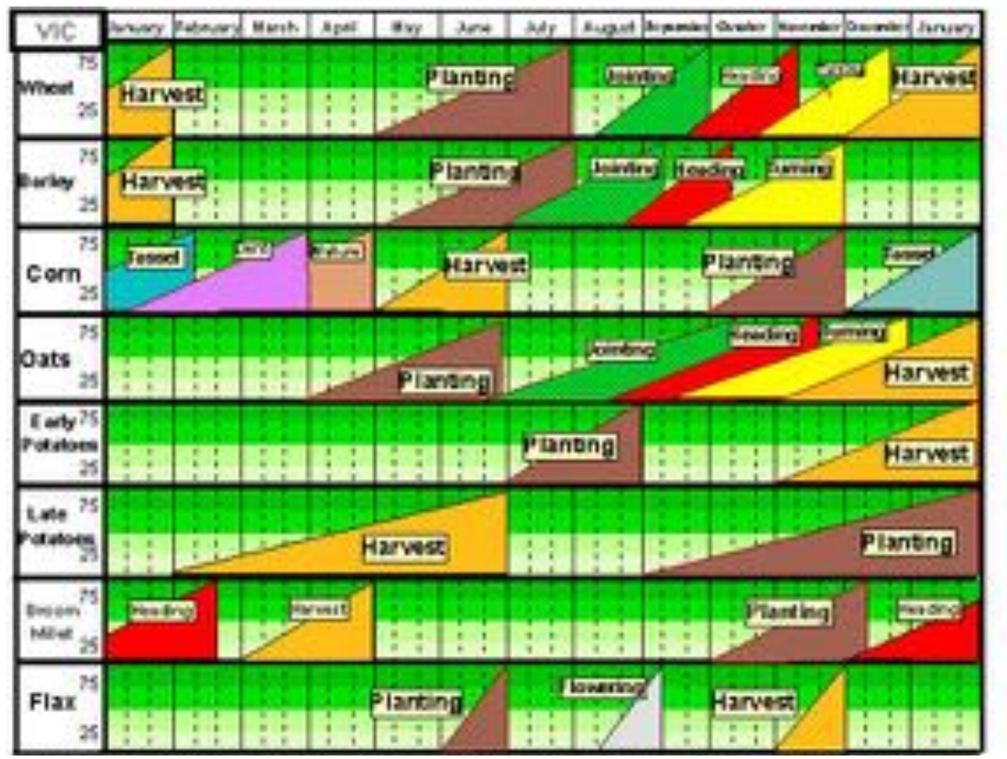
Exposure

Crop calendar

The Cultivated Area Units will be characterized by using the crop calendar to define crop seasonality.



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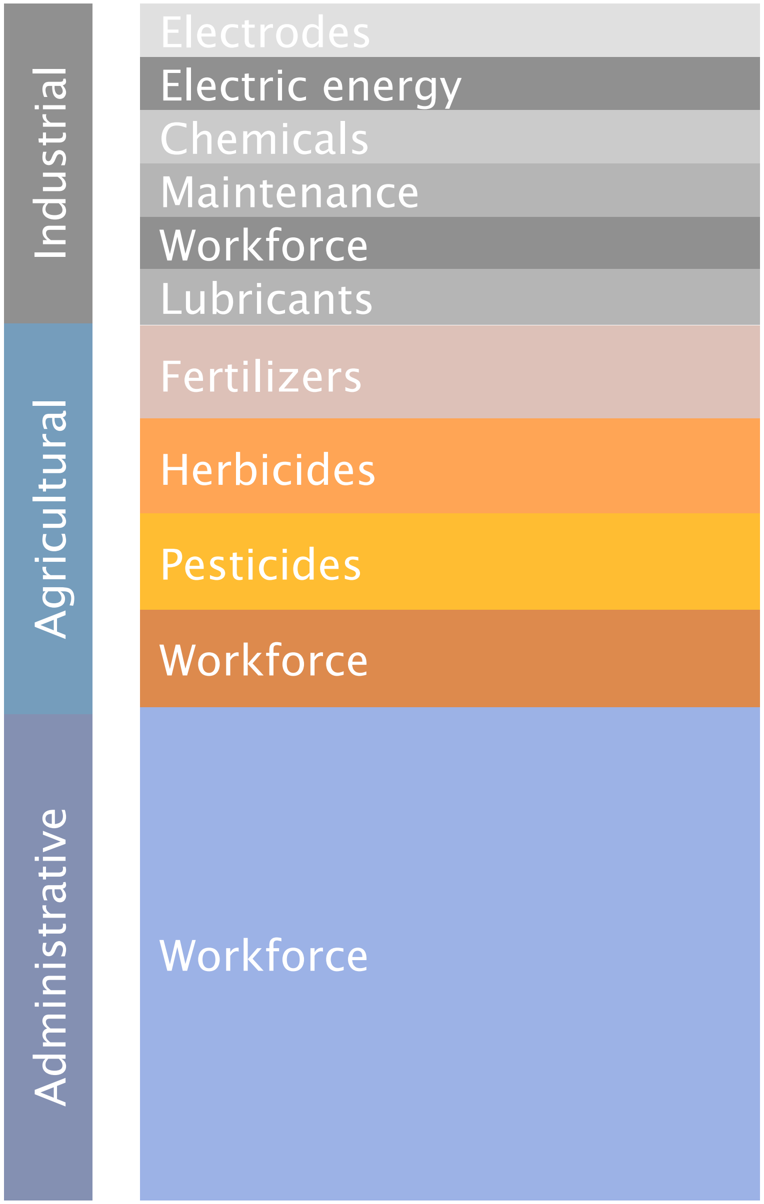
Exposure

Crop valuation

Crop production costs include expenses associated with raw materials (seeds, fertilizers, irrigation), labor and machinery investments.



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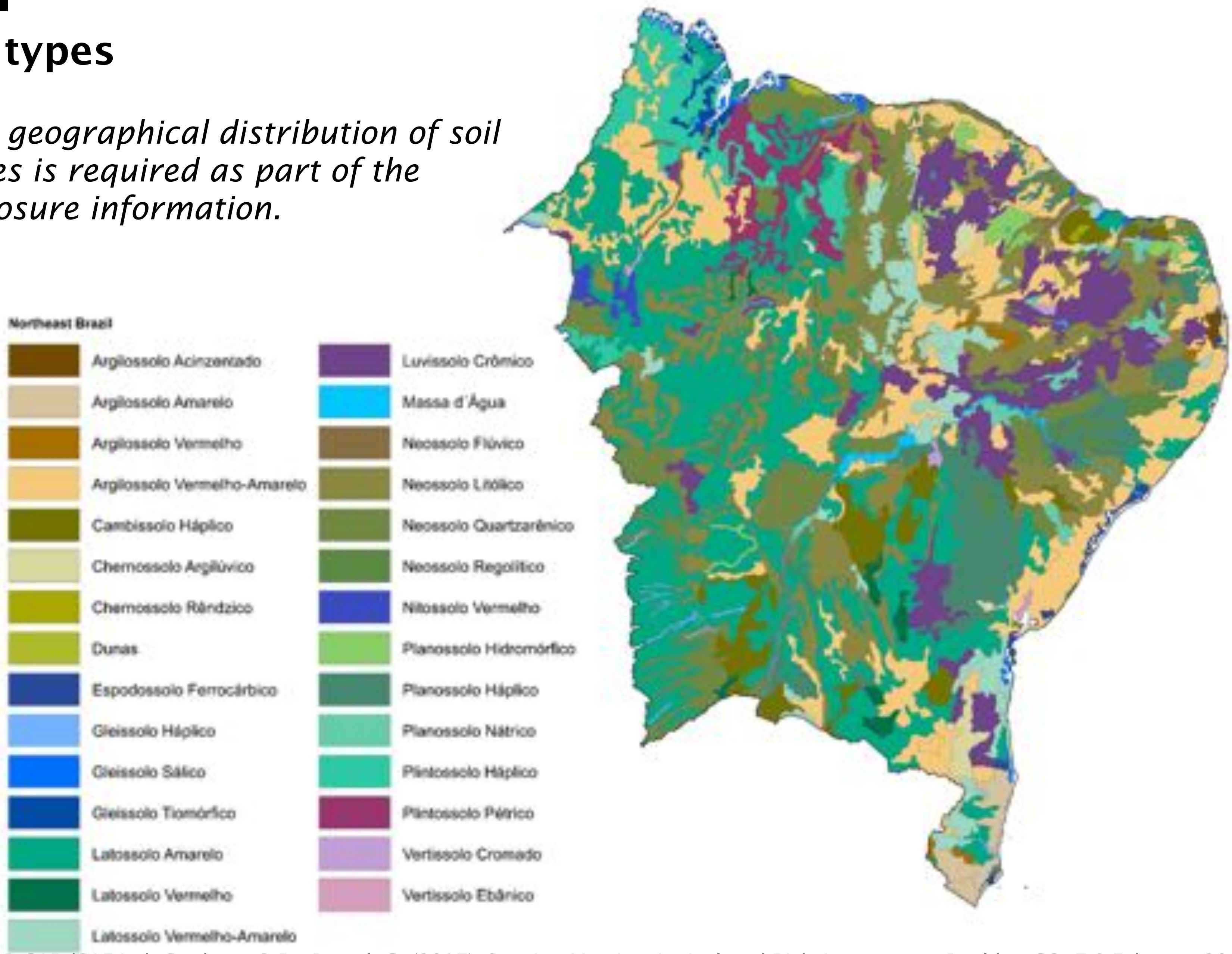
Exposure

Soil types

The geographical distribution of soil types is required as part of the exposure information.



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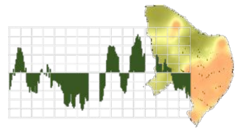
Probabilistic Risk Assessment

Probabilistic Risk Assessment

Inputs

Hazard		*Drought scenarios*
Crop vulnerability		*Yield response to water*
Exposed elements database		*Cultivated land units*

Outputs

Risk metrics		*Loss exceedance curve* *Average annual loss (AAL)* *Probable maximum loss (PML)*

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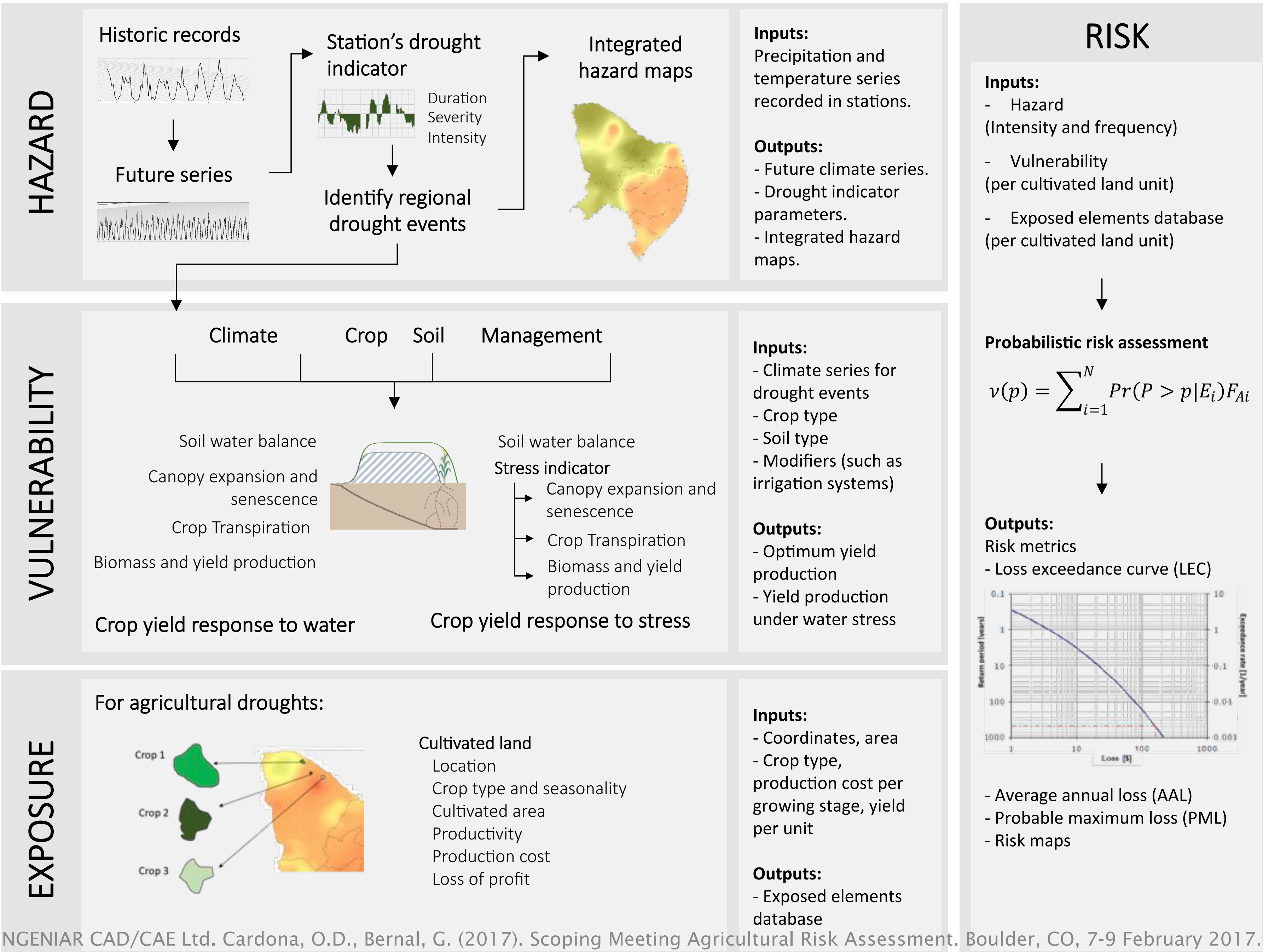

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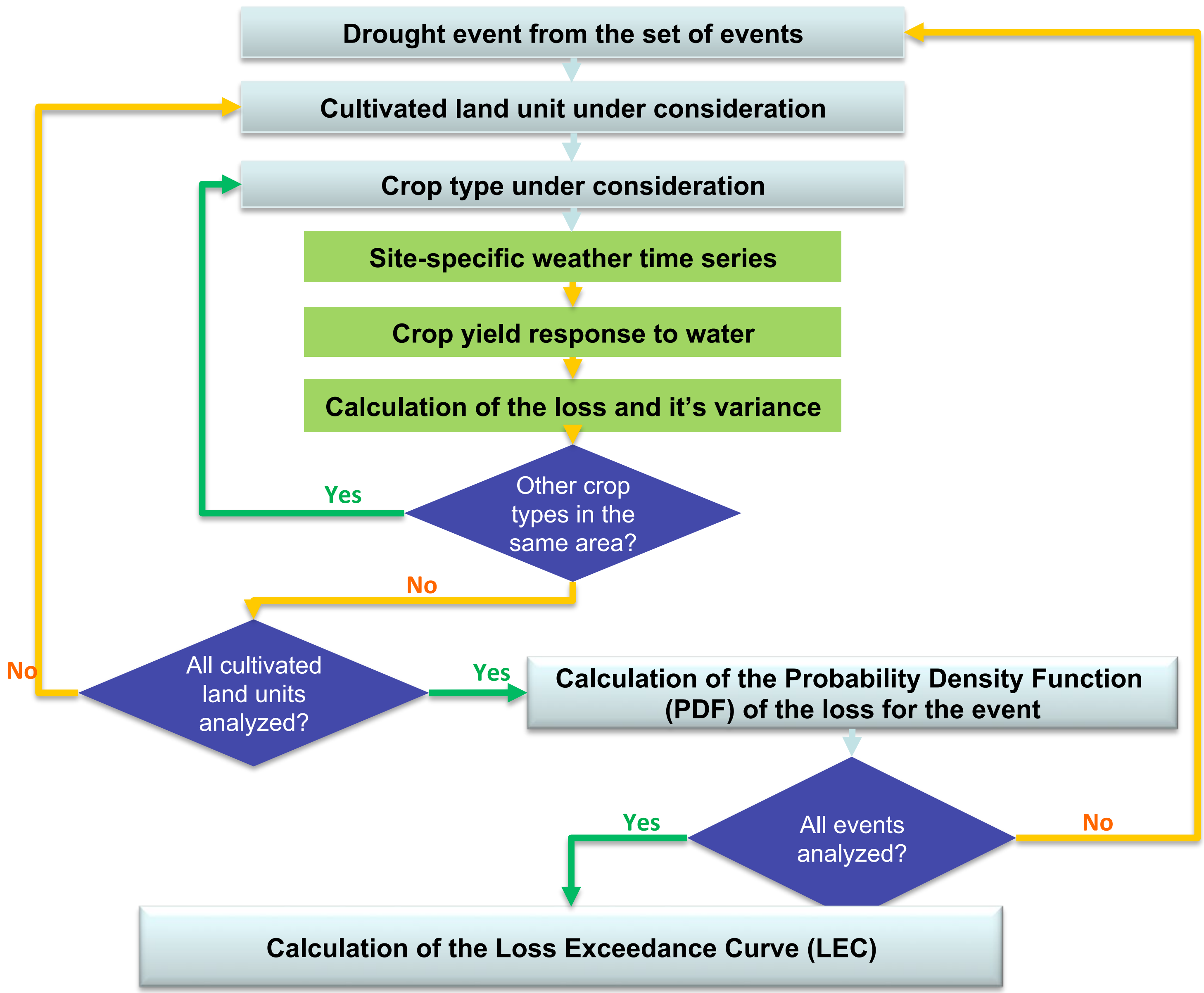
Probabilistic Risk Assessment



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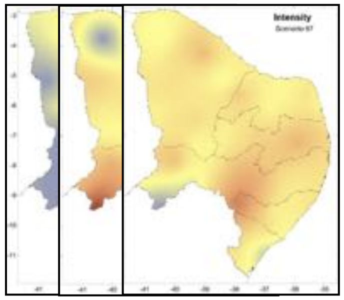
Probabilistic Risk Assessment

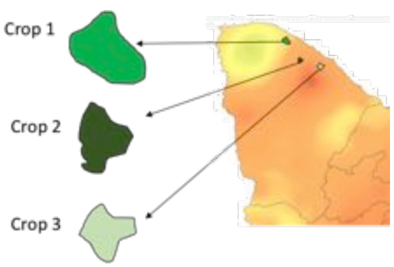
$$E(l \mid Event_i) = \sum_{i=1}^{NE} E(l_j)$$ *Loss aggregation*

$$\sigma^2(l \mid Event_i) = \sum_{j=1}^{NE} \sigma^2(l_j) + 2 \sum_{\substack{k=1 \\ k<j}}^{NE-1} \sum_{j=2}^{NE} \mathrm{cov}(l_k, l_j)$$

Hazard

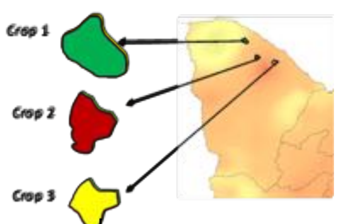


Exposure



Vulnerability

Loss



Risk
PDF of the loss for each scenario

Loss by scenario

Production

Economic

Area of the cultivated unit

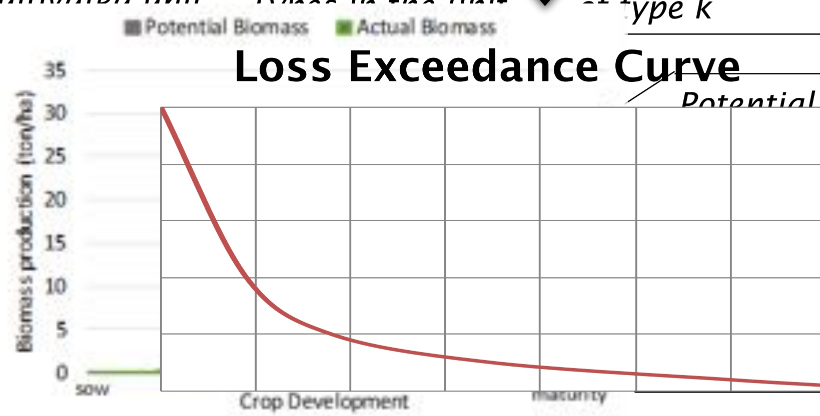
Number of Crop Types in the unit

Participation (%) of type k

Potential yield of … scenario i

… of type … rio i

Loss Exceedance Curve



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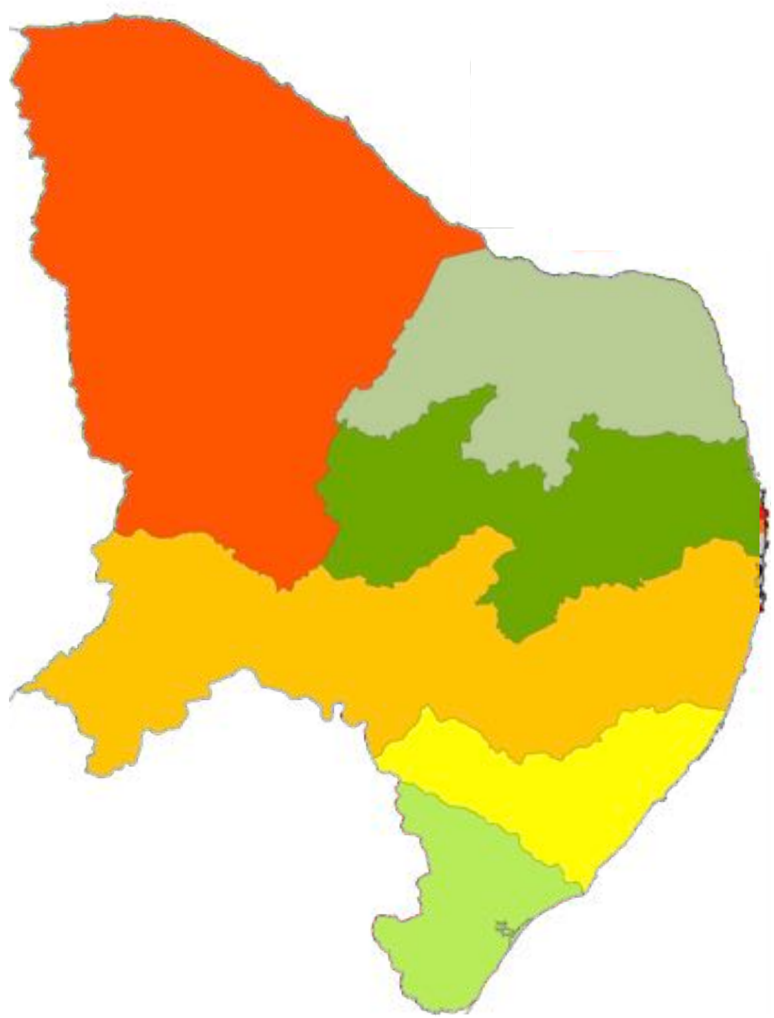
Probabilistic Risk Assessment

Aggregation of losses



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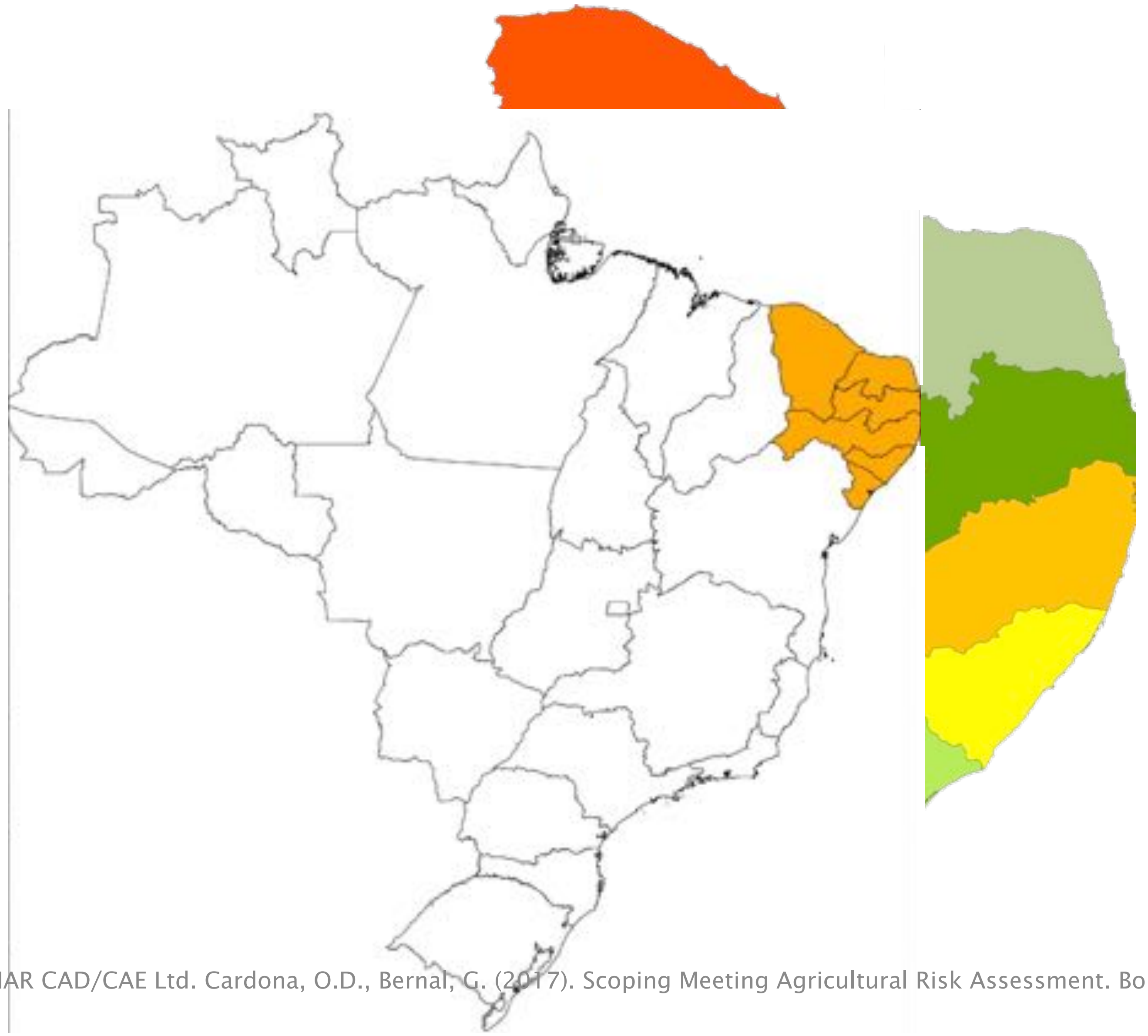
Probabilistic Risk Assessment

Aggregation of losses



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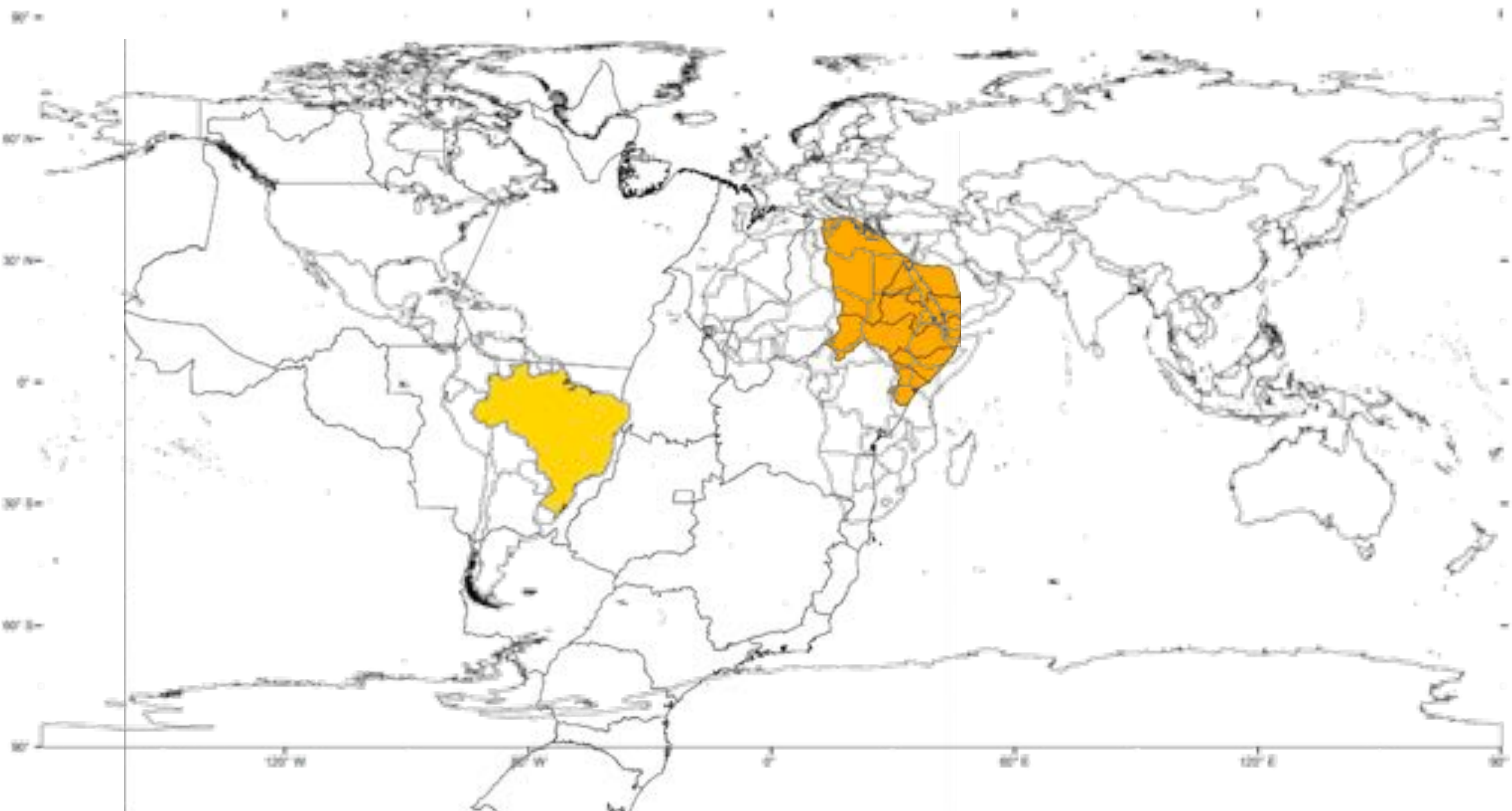
Probabilistic Risk Assessment

Aggregation of losses



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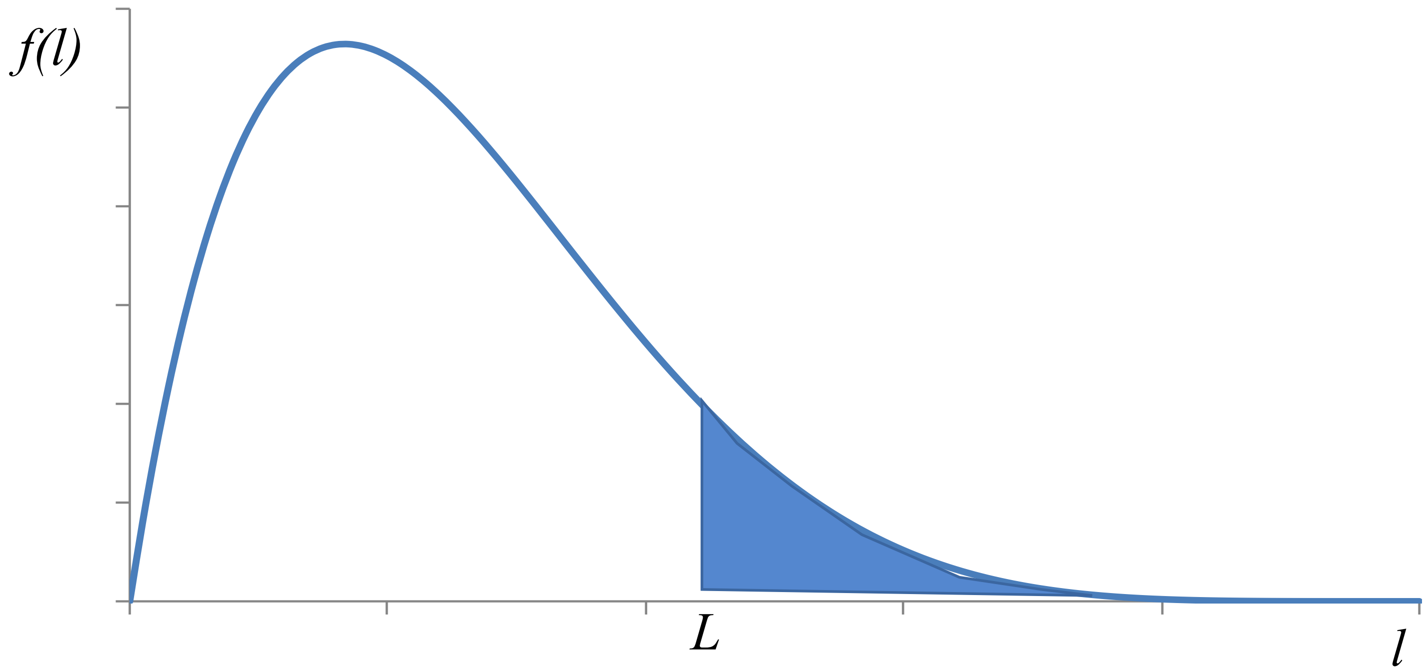
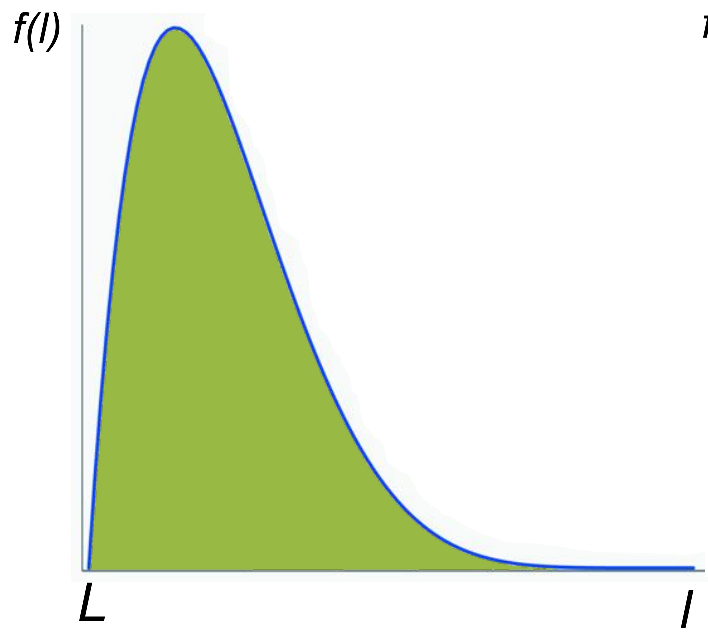
Probabilistic Risk Assessment

PDF of the loss for one scenario



$$\Pr\left(l \geq L\right) = \int_{L}^{\infty} f\left(l\right) dl$$

Probabilistic Risk Assessment

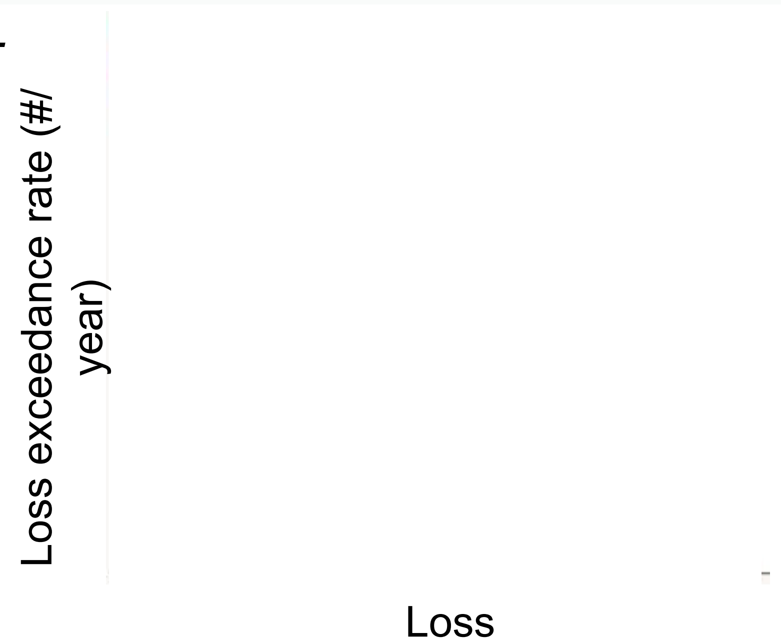


Loss exceedance rate

Loss exceedance probability

$$\nu(l) = \sum_{i=1}^{N} \Pr(l \geq L \mid E_i) \cdot F_i$$

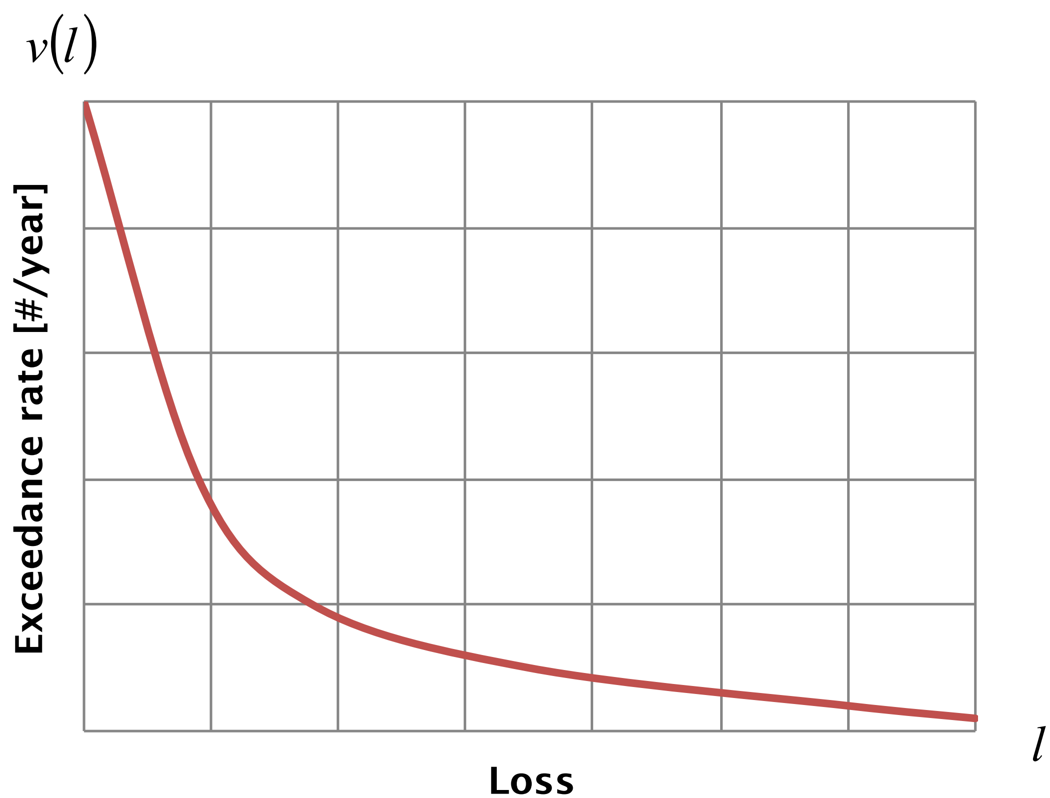
Occurrence frequency of each scenario



Probabilistic Risk Assessment

Loss Exceedance Curve (LEC)

Sets the annual rate of excess of a given loss value



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Probabilistic Risk Assessment

Return period

Average time needed for reaching or exceeding a loss value, considering a large enough time window

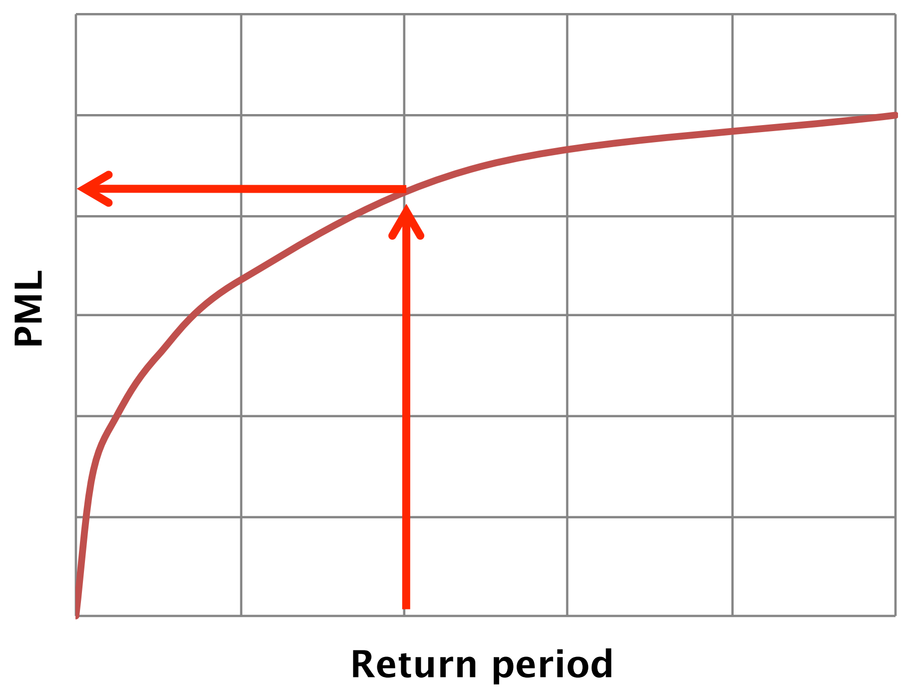
$$Tr = \frac{1}{v(l)}$$

It is computed as the inverse of the exceedance rate

Probabilistic Risk Assessment

Probable Maximum Loss (PML)

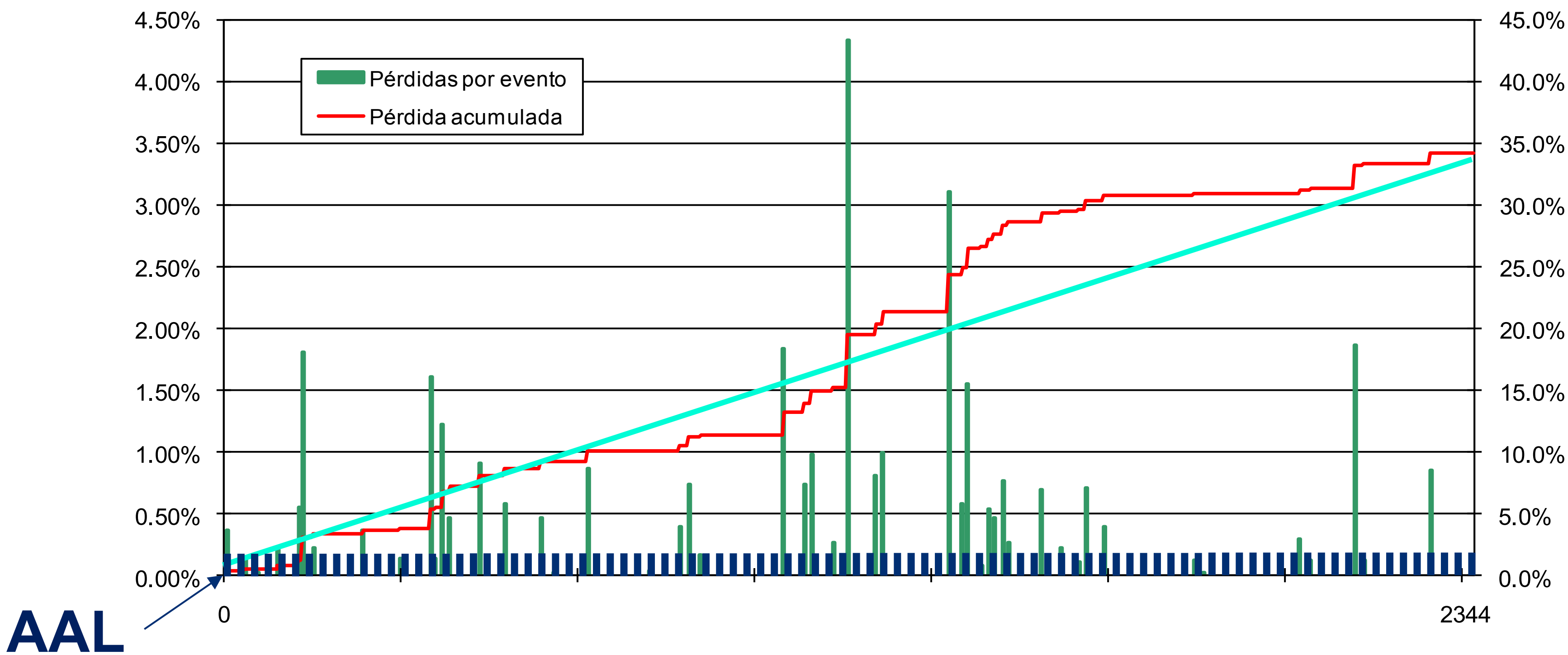
It is a loss that doesn't occur frequently (related to long return periods)



Probabilistic Risk Assessment

Average Annual Loss (AAL)

It represents the amount that has to be paid annually in order to cover future expected losses.



Loss and time between events: unknown

Probabilistic Risk Assessment

Risk information derived from the LEC

The LEC contains all the information required to rigorously characterize the loss occurrence process

LEC

$\nu(l)$

- Annual Average Loss $= \int_0^\infty \nu(l)\,dl$
- Loss exceedance probability within a time frame (T_{exp}) $= 1 - e^{-\left(T_{\exp}\cdot\nu(l)\right)}$
- PDF of any loss event $= -\dfrac{1}{\nu(0)}\dfrac{d\nu(l)}{dl}$
- Probability of exceeding a loss level during the next event $= \dfrac{\nu(l)}{\nu(0)}$
- PDF of the time until next event $= \nu(l)e^{-\nu(l)t}$
- Probability that the number of events to occur in the next T years that excess a loss value l, equals n $= \dfrac{\left(\nu(l)T\right)^n e^{-\nu(l)T}}{n!}$

Probabilistic Risk Assessment

A holistic approach

The LEC provides information on direct physical losses. This metrics can me "amplified" by incorporating other aspects related to risk.

- ✓ *Physical risk*
- ✓ *Social, economical and ecological fragilities*
- ✓ *Lack of resilience or ability to cope and recover*

1st Order EFFECTS

Potential damage on crops

2nd Order EFFECTS

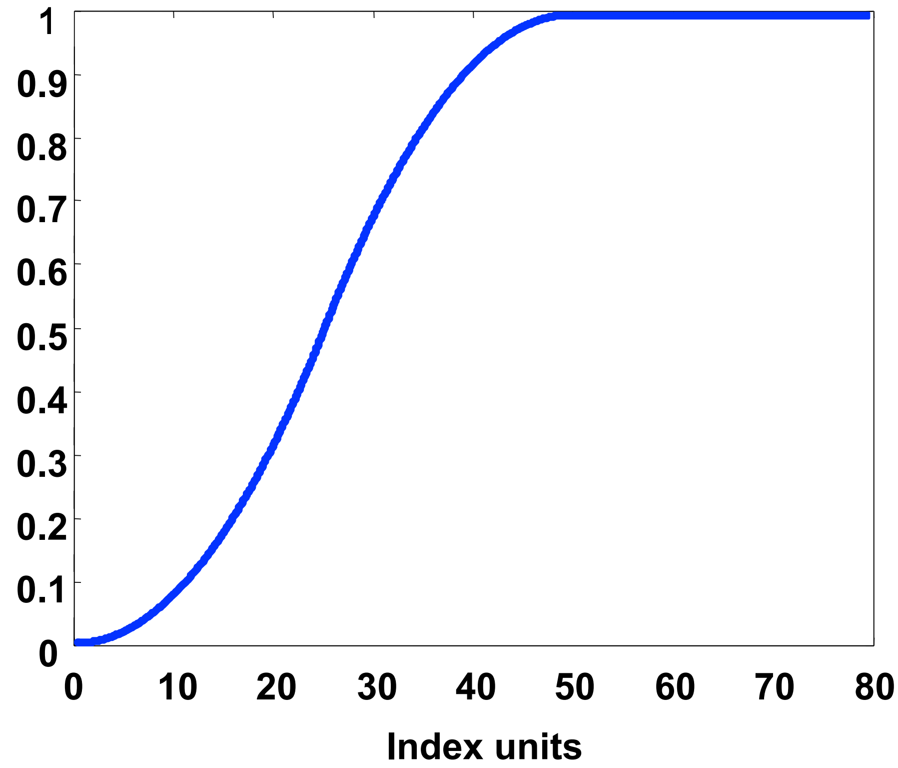
Potential Socio-ecological and Economic Impact on Communities-Organizations

Probabilistic Risk Assessment

A holistic approach

Identification and escalation of non-measurable variables that reflect risk factors

Social aspects
Xs1, Xs2, …. , Xsn
Economic aspects
Xe1, Xe2, …. , Xen
Infrastructural aspects
Xi1, Xi2, …. , Xin
Other aspects (governability, security…)
Xo1, Xo2, …. , Xon



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Probabilistic Risk Assessment

A holistic approach

Assessment of the influence of each variable – Analytic Hierarchy Process

Social aspects	Weights
Xs1, Xs2, …. , Xsn	Ws1, Ws2, …. , Wsn
Economic aspects	**Weights**
Xe1, Xe2, …. , Xen	We1, We2, …. , Wen
Infrastructural aspects	**Weights**
Xi1, Xi2, …. , Xin	Wi1, Wi2, …. , Win
Other aspects (governability, security…)	**Weights**
Xo1, Xo2, …. , Xon	Wo1, Wo2, …. , Won

Aggravating coefficient

$$F = \sum_{i=1}^{N} X_i \cdot W_i$$

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Probabilistic Risk Assessment

A holistic approach

Total risk

Aggravating coefficient

Total risk

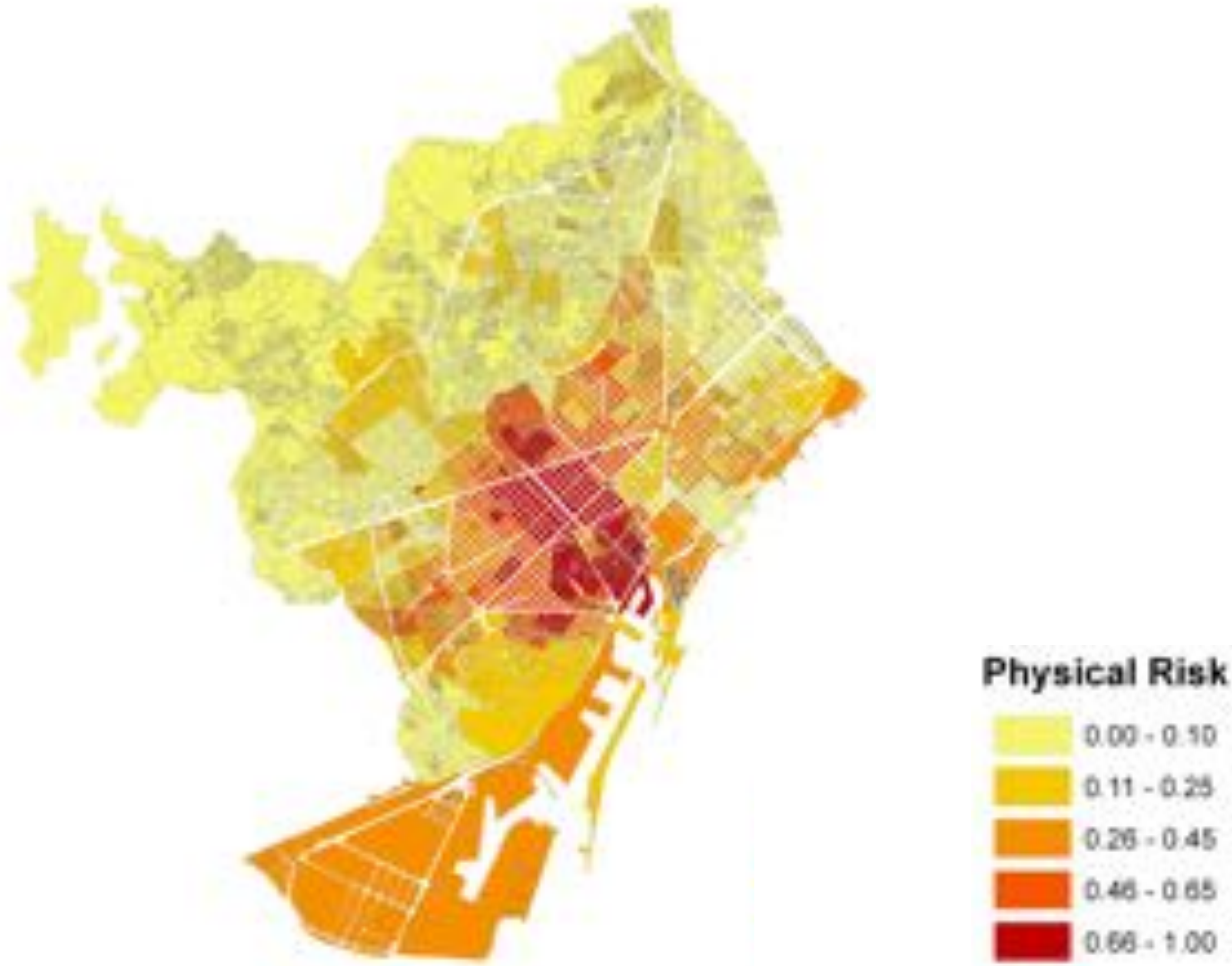
$$R_T = R \cdot (1 + F)$$

Physical risk metric

Probabilistic Risk Assessment

A holistic approach

Total risk



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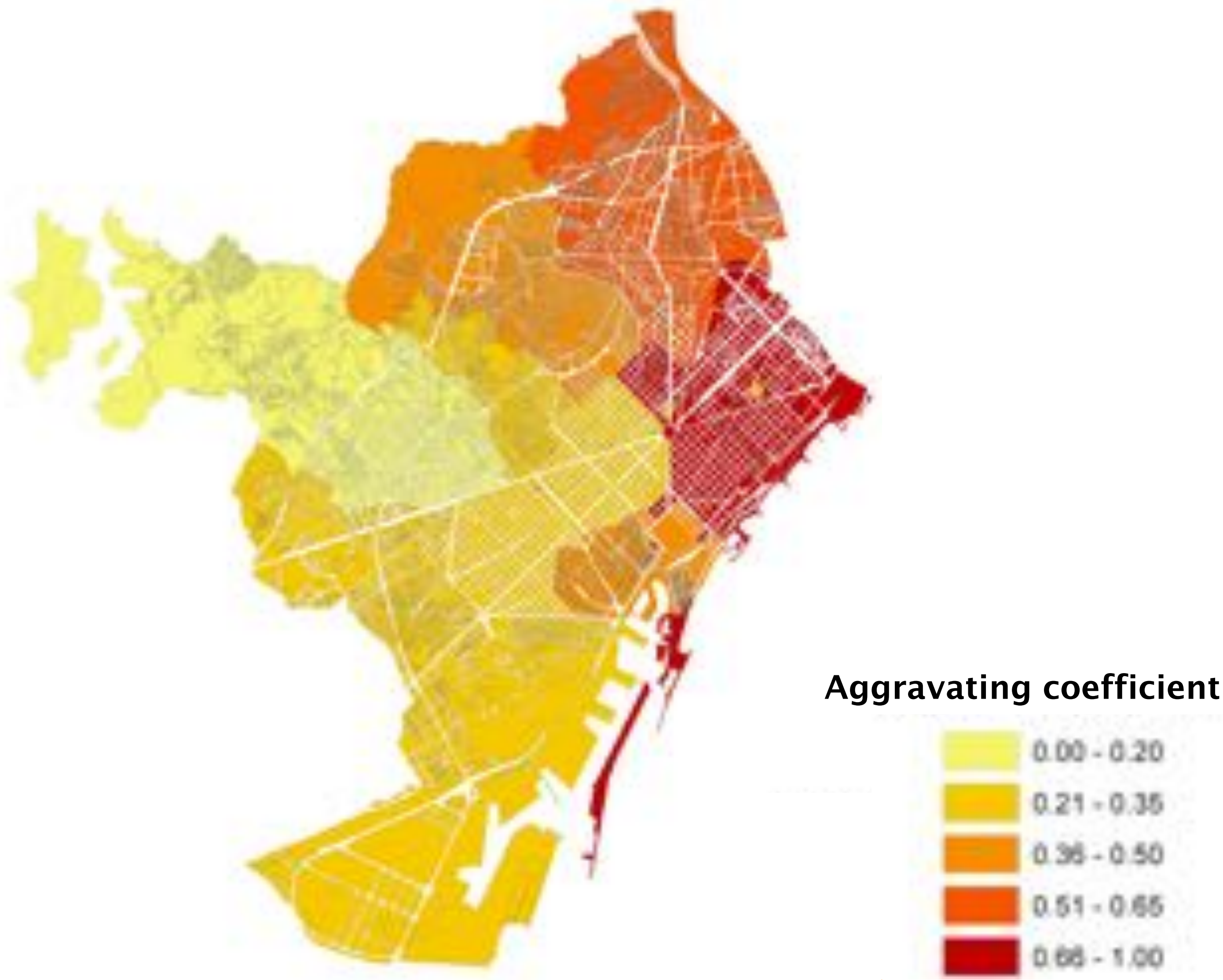
Probabilistic Risk Assessment

A holistic approach

Total risk



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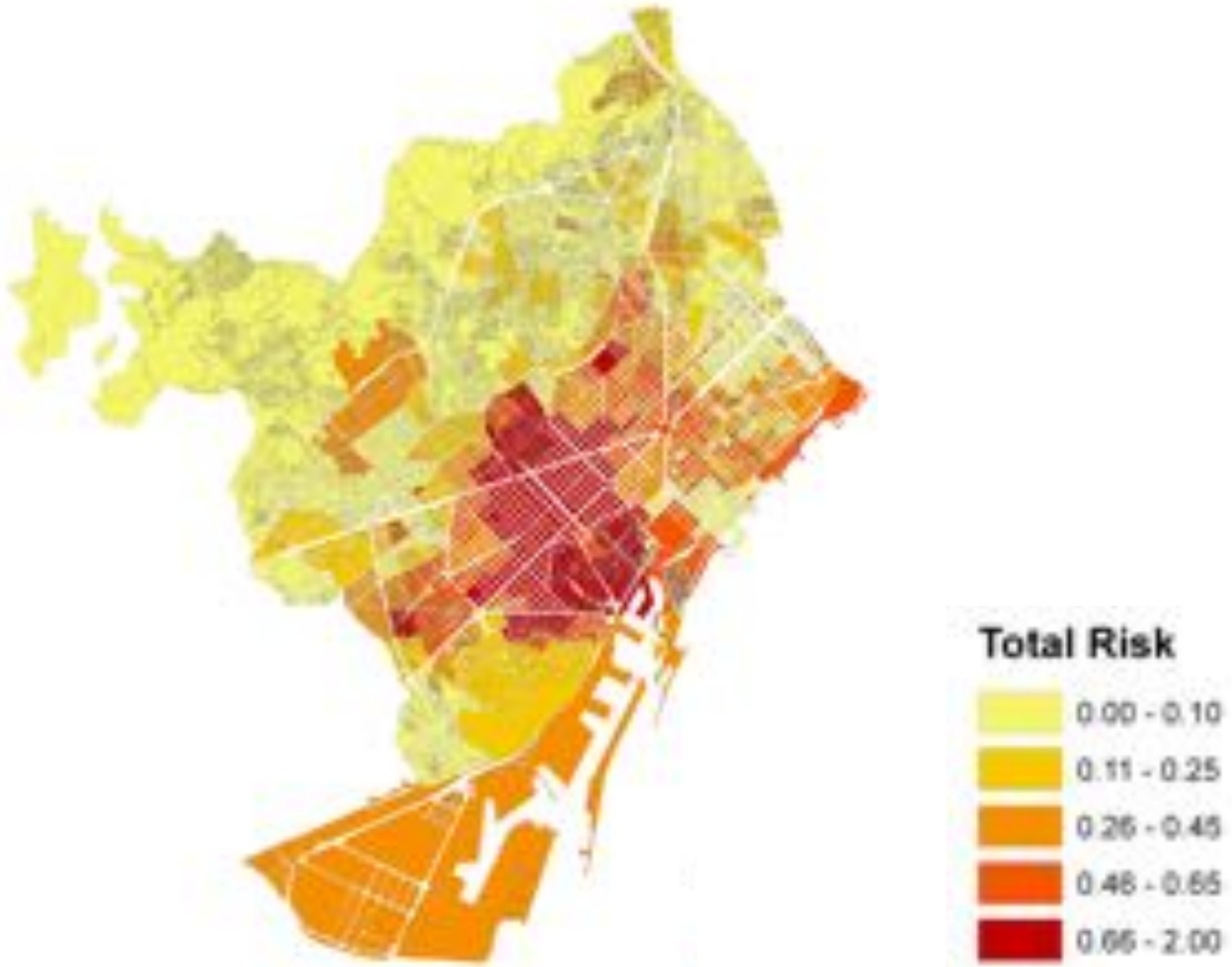
Probabilistic Risk Assessment

A holistic approach

Total risk



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Drought Risk Assessment

Final remarks

Drought risk is evaluated considering:

- ✓ *The uncertainty associated with the probability of occurrence of the hazardous event,*
- ✓ *The variability of the intensity of the hazard scenario throughout space and time, and*
- ✓ *The loss caused at each exposed element given its vulnerability.*

Drought Risk Assessment

Final remarks

- ✓ *This methodology considers all possible events that could occur (and that have not necessarily occurred yet) and integrates them probabilistically.*

- ✓ *This probabilistic representation of drought widens the scope of how the drought hazard, vulnerability and exposure can be understood and estimated.*

- ✓ *Probabilistic drought risk assessments can become the reference frame for territorial decisions and for the agricultural sector.*