Why agrometeorology is like a good cooking recipe?

Because it's all about mixing the right amount of sun, water, soil, and a pinch of wind — too much or too little of any ingredient, and the crop gets spoiled!

Agricultural Meteorology and Climate Services: *from weather impacts to integrated climate-crop modelling*

Robel Takele

14 December 2025

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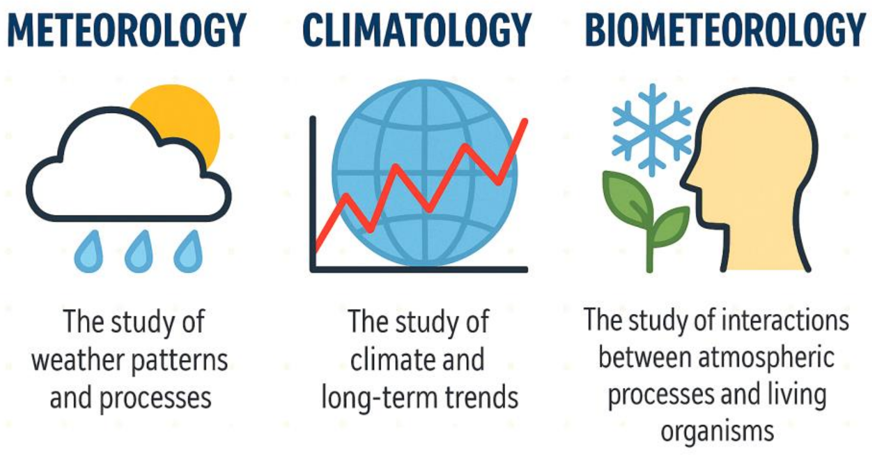
Outline

- Agricultural Meteorology: practices and services
- Impact of Weather Events on Crop Production
- Integrated Dynamical Climate-Crop Modelling Systems
- Soil Water Balance Models
- Characterizing the Wet Season Calendar.
- Predicting Agronomic Onset of the Growing Season.
- **Case Study:** *using AquaBEHER seasonal forecast for planting decisions.*

Weather Vs Climate ?

Weather: Physical state of the atmosphere at a given place and given time in a short time.

Climate: Long term regime of atmospheric variables of a given place or area.



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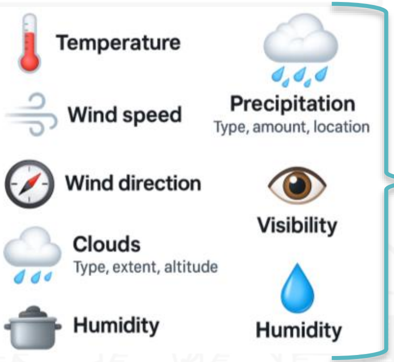
Agricultural Meteorology: *practices and services*

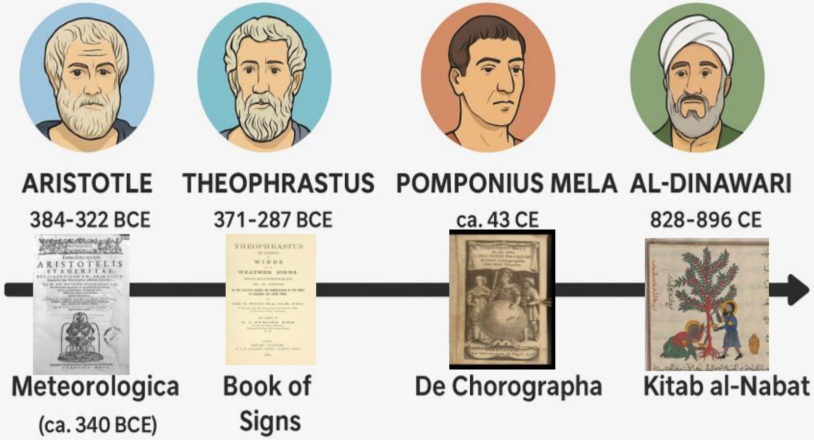
Meteorology Greek word "**Meteoro**" means 'above the earth's surface' (atmosphere) "**logy**" means "indicating science" **Meteoro + logy = Meteorology.**

is the study of *phenomena of the atmosphere* – includes the dynamics, physics, and chemistry of the atmosphere.



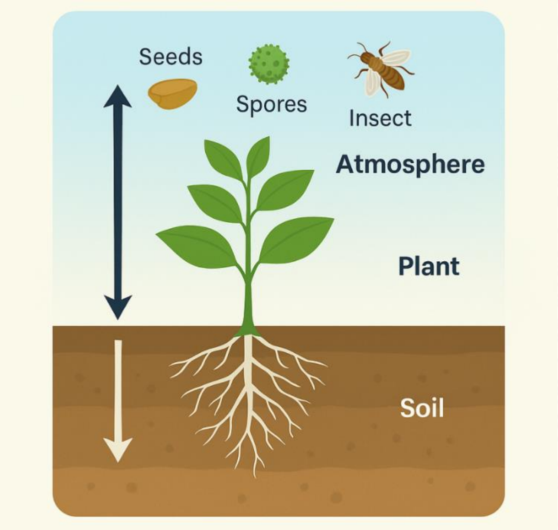
What we want to know ?

- Trends in all of these.
- Timing of significant changes.
- Frequency, occurrence of **extreme or** unfavorable events.



Agricultural Meteorology: *practices and services*

A branch of meteorology that examines the effects and impacts of weather and climate on crops, rangeland, livestock, and various agricultural operations.



Scope of Agricultural Meteorology

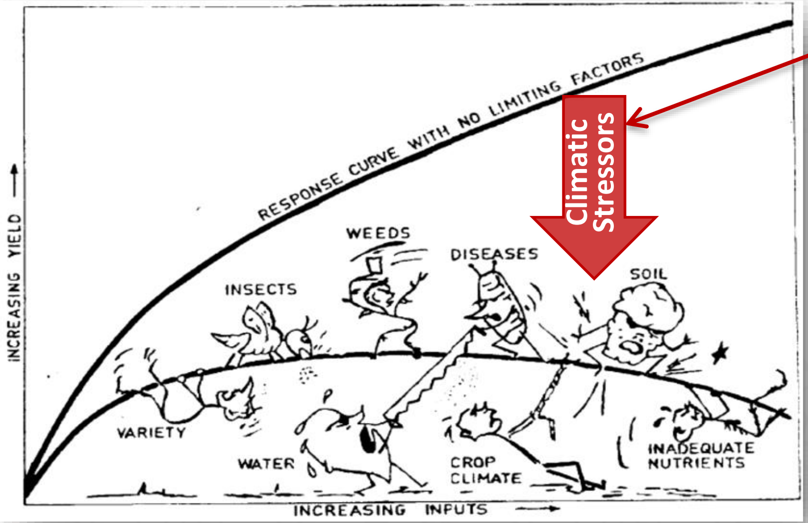
Agricultural meteorology addresses topics that often require an understanding of biological, physical, and social sciences.

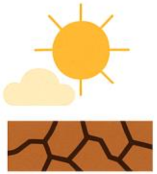
Main Issues:

- ✓ **Characterization of Agricultrural Climate.**
- ✓ **Stability/Stablize on Crop/Agricultural Production.**

Impact of Weather Events on Crop Production

Weather events play a critical role in determining agricultural productivity.
Understanding these impacts is essential for food security and adaptation strategies.





DROUGHT
Water stress reduces crop yields

HEAVY RAINFALL
Excess moisture leads to root damage

FROST
Cold temperatures cause frost injury

HEATWAVE
High temperatures result in crop stress

Climatic stressors that are critical climatic determinants that govern the performance of crop growth can be quantified through indices called ***Agroclimatic Indices***climas)

Impact of Weather Events on Crop Production: *bioclimatic variables*

Bioclimatic variables are climate-based indicators derived from monthly temperature and precipitation data.

Represent:

- Annual trends (e.g., mean annual temperature, annual precipitation).
- Seasonality (e.g., annual range in temperature and precipitation).
- Extreme or limiting environmental factors (e.g., temperature of the coldest and warmest month).

Applications:

- Species distribution modeling.
- Biodiversity and conservation planning.
- Crop suitability and agroecological zoning.
- Land use and ecological niche modeling.

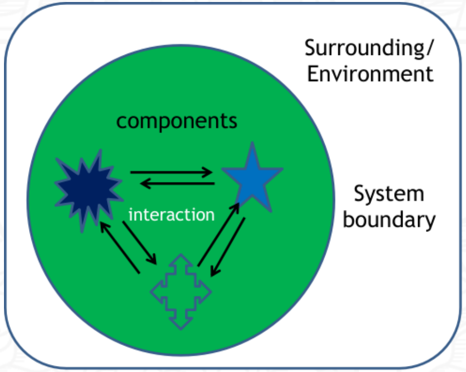
Code	Variables
BIO1	Annual Mean Temperature
BIO2	Mean Diurnal Range (Mean of monthly)
BIO3	Isothermality
BIO4	Temperature Seasonality
BIO5	Max Temperature of Warmest Month
BIO6	Min Temperature of Coldest Month
BIO7	Temperature Annual Range
BIO8	Mean Temperature of Wettest Quarter
BIO9	Mean Temperature of Driest Quarter
BIO10	Mean Temperature of Warmest Quarter
BIO11	Mean Temperature of Coldest Quarter
BIO12	Annual Precipitation
BIO13	Precipitation of Wettest Month
BIO14	Precipitation of Driest Month
BIO15	Precipitation Seasonality
BIO16	Precipitation of Wettest Quarter
BIO17	Precipitation of Driest Quarter
BIO18	Precipitation of Warmest Quarter
BIO19	Precipitation of Coldest Quarter

Integrated Dynamical Climate-Crop Modelling Systems

System Environment and Boundary

What is a system ?

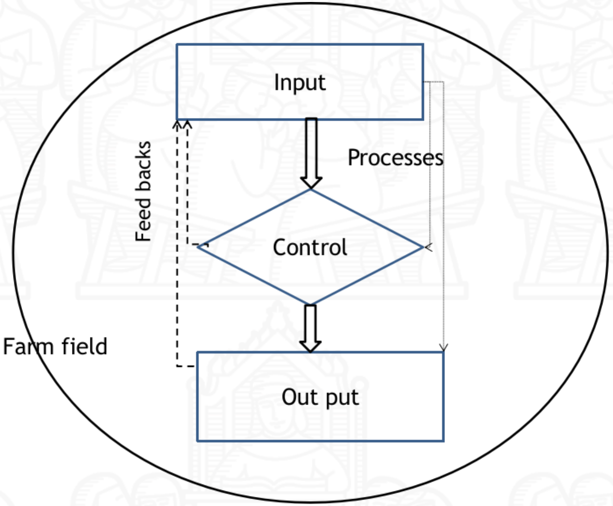
A system is a set of components and their interrelationships that are grouped together by a person or a group of persons for the purposes of studying some part of the real world.



BOUNDARY AND INTERFACE

A system has an environment as well as components and interactions among them.

Elements of a system



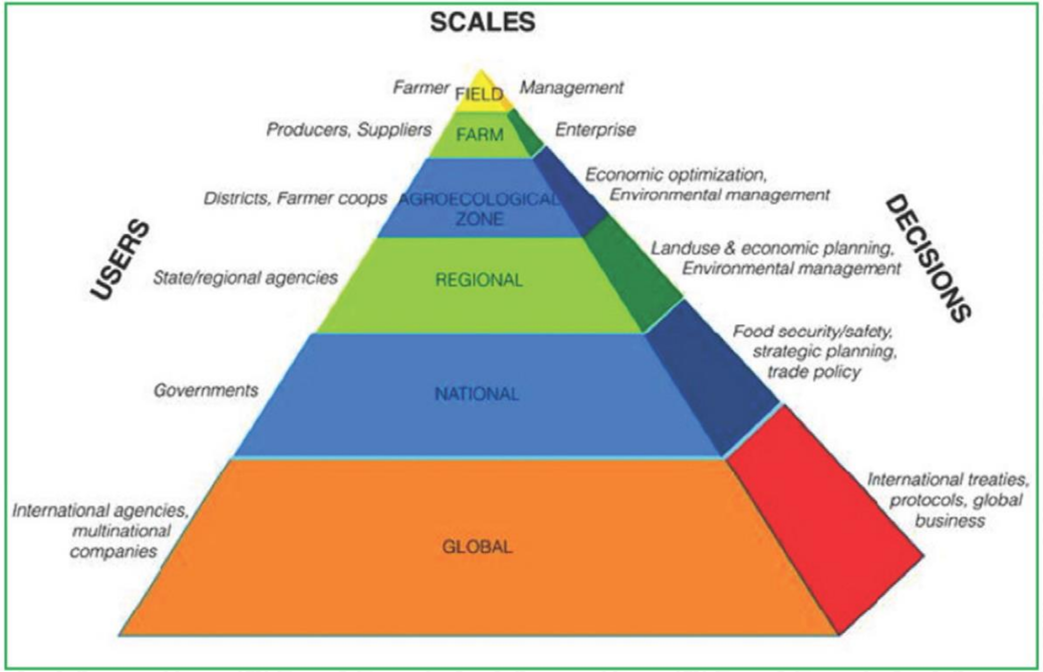
A system should be defined by its:

- ***Boundaries;*** the limits that identify its components,
- ***processes and interrelationships;*** when it interfaces with another system.

Integrated Dynamical Climate-Crop Modelling Systems

Characteristics of agricultural system models:

- Intended use of models/purposes for model development
- Approaches for modeling agricultural systems
- Their target scales;Spatial and temporal scales of agricultural system models.



Integrated Dynamical Climate-Crop Modelling Systems

After defining system and its boundary, eg In agriculture crop field is chosen as a system, key variables in the system are defined:

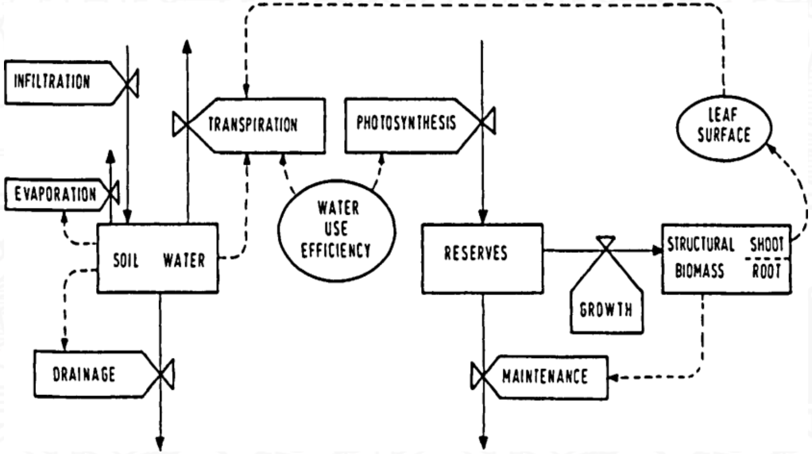
❖***State variables:*** those which can be measured or quantified; e.g. soil moisture content, crop yield.

❖***Rate variables:*** the rates of different processes operating in a system; e.g. photosynthesis rate, transpiration rate.

❖***Deriving variables:*** the variables which are not part of the system but that affect the system; e.g. sunshine, temperature, rainfall.

❖***Auxiliary variables:*** are the intermediate products; e.g. dry matter partitioning.

Relational Diagram



Integrated Dynamical Climate-Crop Modelling Systems

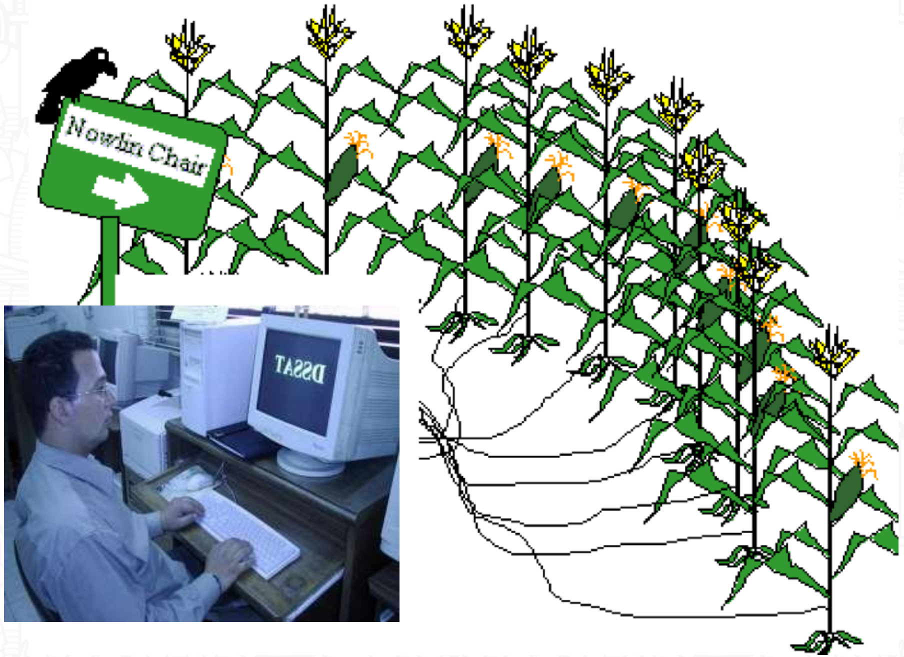
***Model:* It is a simplified description**

(often, a mathematical representation)

of a system to assist

calculations and predictions.

In the present context, 'model' is expressed as a computer program that can be repeatedly run several times for computing several designed mathematical or statistical expressions (equations) governing crop growth-environment relations, given appropriate input data.



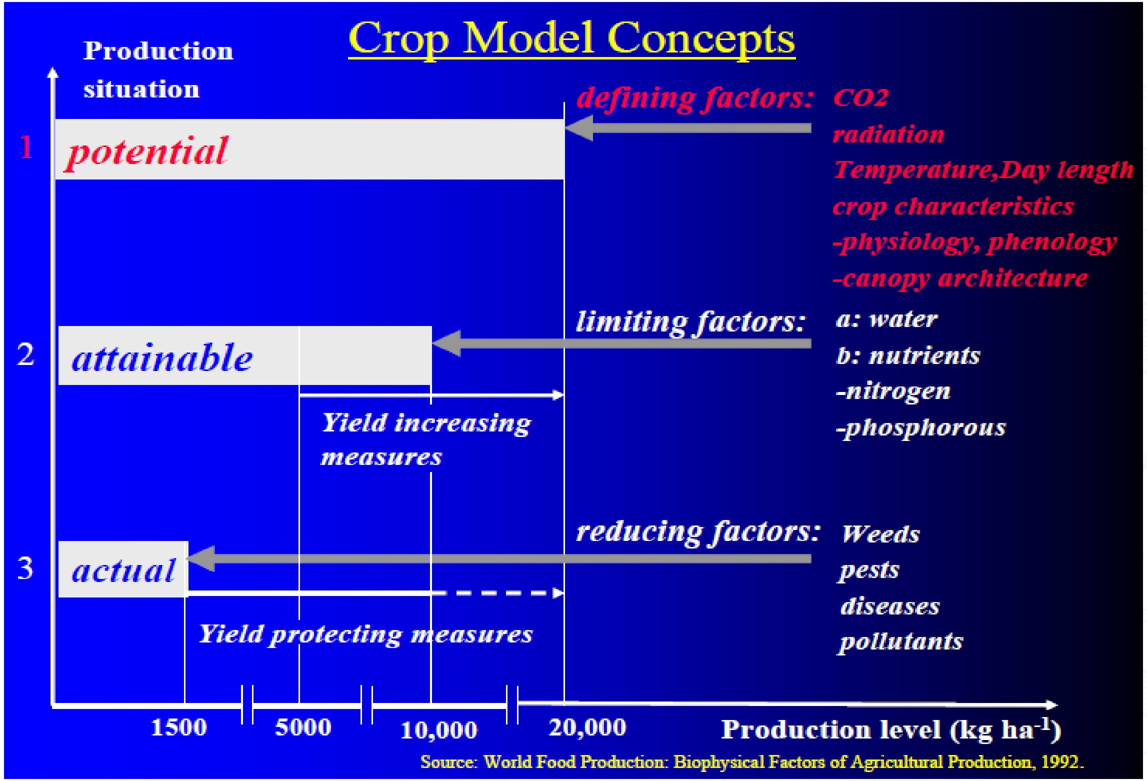
"Growing the crop on the computer"

Integrated Dynamical Climate-Crop Modelling Systems: *types*

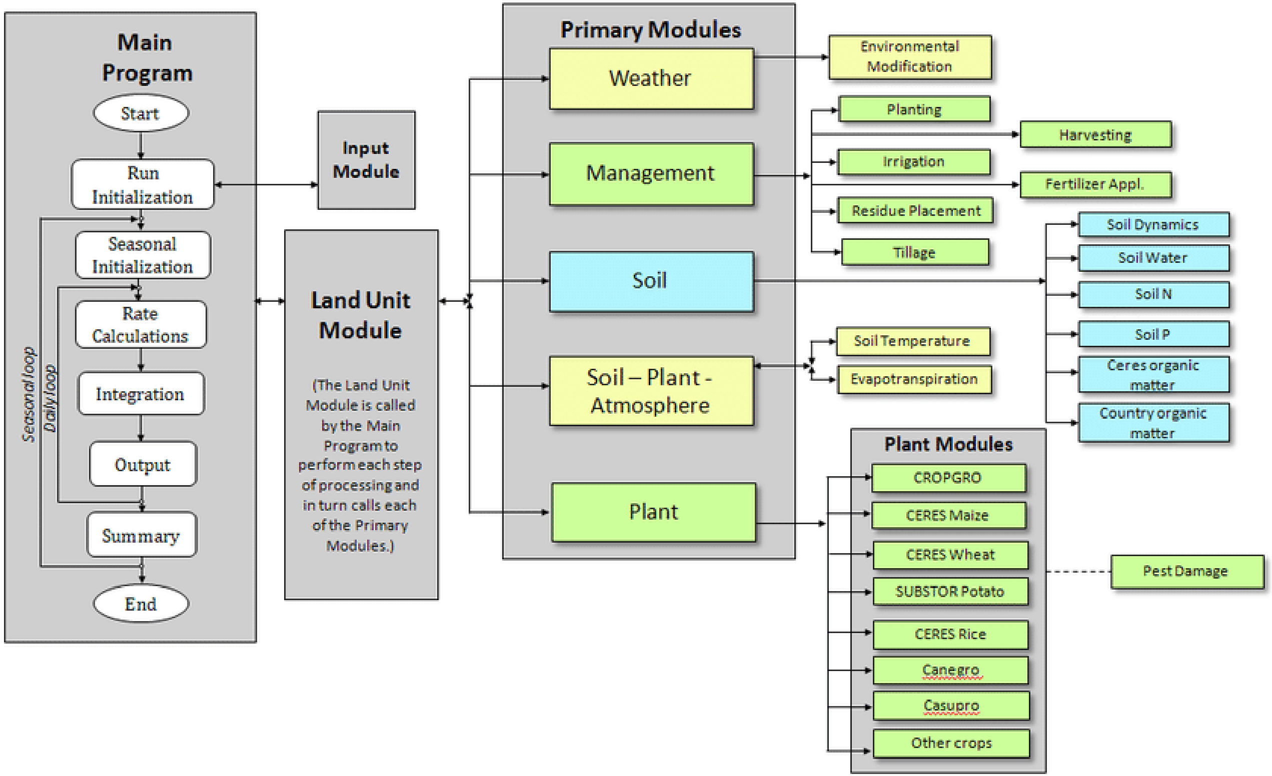
Statistical Models	Mechanistic Models	Deterministic Models
Use statistical relationships between variables (e.g., climate, soil) and crop yields	Describe biological and physical processes that control crop growth	Give a single fixed output for a given input

Stochastic Models	Dynamic Models	Simulation Models
Include randomness/ probability to simulate variability	Simulate crop growth as it changes over time	Computer-based models used to simulate crop development and yield

Integrated Dynamical Climate-Crop Modelling Systems



Integrated Dynamical Climate-Crop Modelling Systems



Integrated Dynamical Climate-Crop Modelling Systems: *genetic coefficients*

※Genetic coefficients are parameters that define the growth, development, and yield potential of a specific crop cultivar within crop simulation models.

※They capture the genetic differences among cultivars, allowing models to simulate how different varieties respond to environmental and management conditions.

Coefficient	Description	BH660	Melkasa-II
P1	Thermal time from seedling emergence to the end of the juvenile stage (degree days above the base temperature of 8°C in the juvenile stage)	370.0	220.0
P2	Photoperiod sensitivity associated with delayed growth under unfavorable long day length condition (no unit)	0.17	0.10
P5	Thermal time from silking to physiological maturity (degree days above the base temperature of 8°C in the maturity stage)	610.0	640.0
G2	Potential maximum number of kernels per plant	630.0	920.0
G3	Kernel filling rate under optimum condition (mg/d)	10.8	7.1
PHINT	Interval in thermal time between successive leaf appearance (degree days above a base temperature of 8°C)	38.90	38.90

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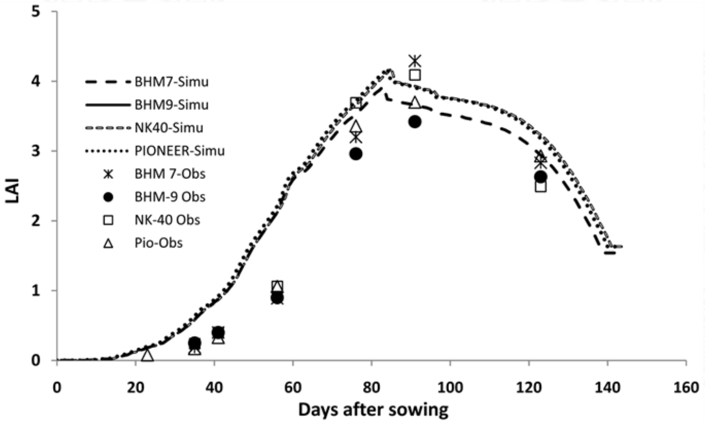
Integrated Dynamical Climate-Crop Modelling Systems: *calibration*

Calibration: Adjusting model parameters so that simulated results match observed field data.

Key steps:

- ✓ Use observed yield, growth stages, biomass data.
- ✓ Modify genetic coefficients and soil parameters.
- ✓ Aim for minimal error between simulated and observed values.



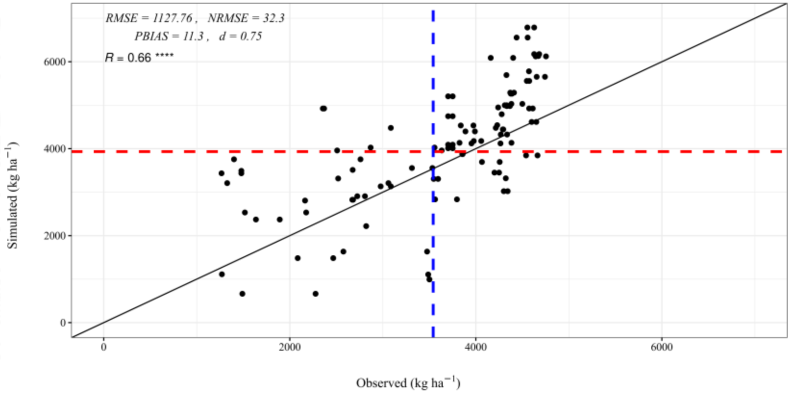
Cultivar	Days to anthesis			Days to maturity			Grain yield ($t \cdot ha^{-1}$)			Tops weight ($t \cdot ha^{-1}$)		
	Obs	Sim.	%Error	Obs	Sim	%Error	Obs.	Sim.	%Error	Obs.	Sim.	%Error
BHM-7	81	80	1.23	142	139	2.11	10.16	10.12	0.39	21.39	20.55	3.90
BHM-9	81	80	1.23	142	139	2.11	10.73	10.43	2.80	22.20	20.85	6.10
PIONEER	82	80	2.44	143	140	2.10	10.94	10.55	3.56	22.21	20.98	5.57
NK-40	82	80	2.44	143	140	2.10	10.83	10.59	2.22	22.22	21.01	5.42

Table 4. Simulated and observed values for four maize cultivars for days to anthesis, days to maturity, grain yield and biomass at harvest (2014-2015, process of calibration).

Ahmed et al, 2017; DOI: 10.4236/ajps.2017.87113

Integrated Dynamical Climate-Crop Modelling Systems: *validation*

Validation: Testing the calibrated model on independent datasets to assess performance.



Key steps:

- ✓ Apply model to different years, sites, or management conditions.
- ✓ Compare predictions with observed data.
- ✓ Statistical tests: RMSE, R^2, d-index.
- ✓ Ensures reliability for decision making.

- ✓ Models and simulations can’t completely re-create real life situations.
- ✓ Not every possible situation have been included in the model.
- ✓ The result depends on how good the model is and how much data was used to create it in the first place.

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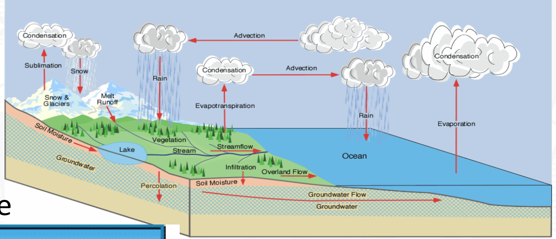
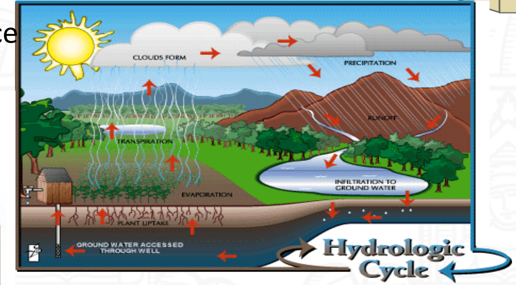
Soil Water Balance Models

The water balance, or water budget is the **balance** between these **inputs** and **outputs**.

Global hydrological cycle

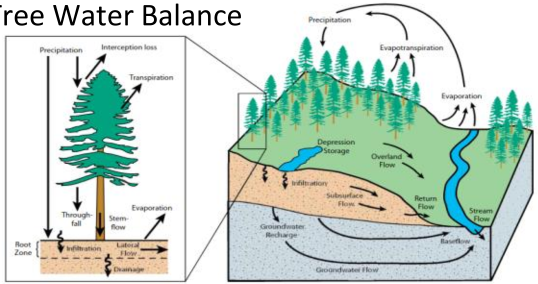


Terrestrial hydrological cycle

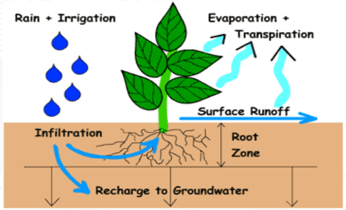


Forest Water Balance

Tree Water Balance



Soil Water Balance



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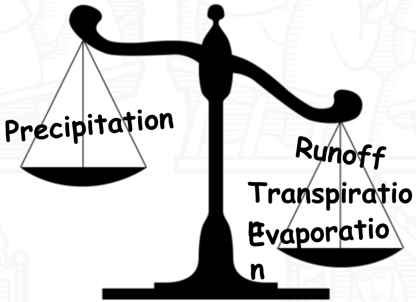
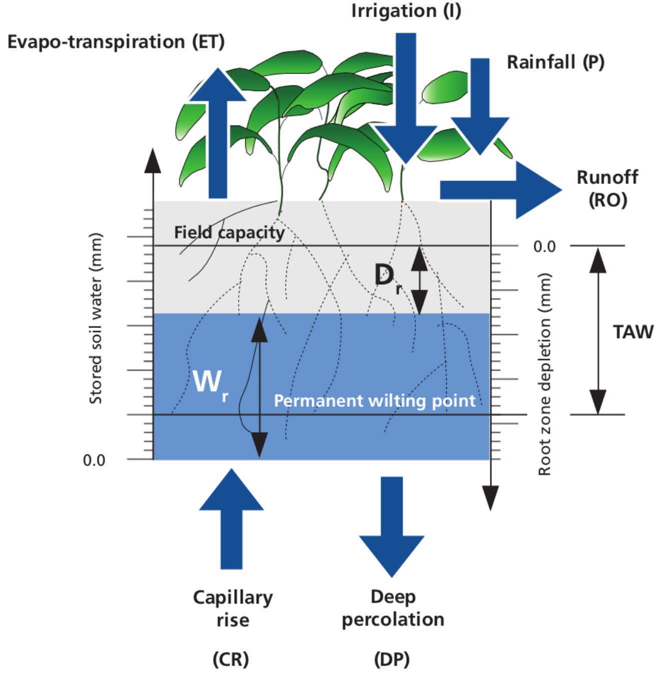
Soil Water Balance Models

$$\Delta SW_i = SW_{i-1} + P_i + I_i + CR_i - RO_i - ET_i - DP_i$$

A simple daily computation for the root zone to account for supply and demand of soil moisture.





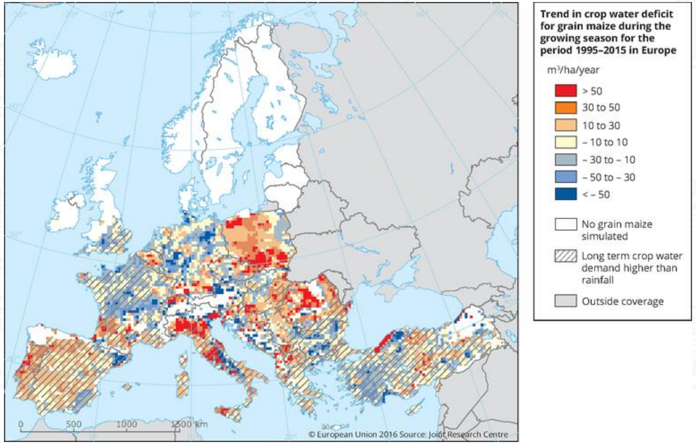
The method consists of assessing the incoming and outgoing water flux into the crop root zone ***(Allen et al. 1998; Ritchie, 1998; Woli et al., 2012).***

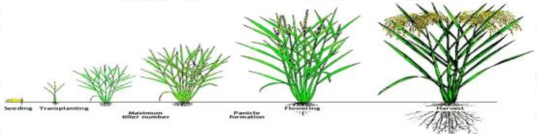
Soil Water Balance Models: *applications*

To explore water-management options:

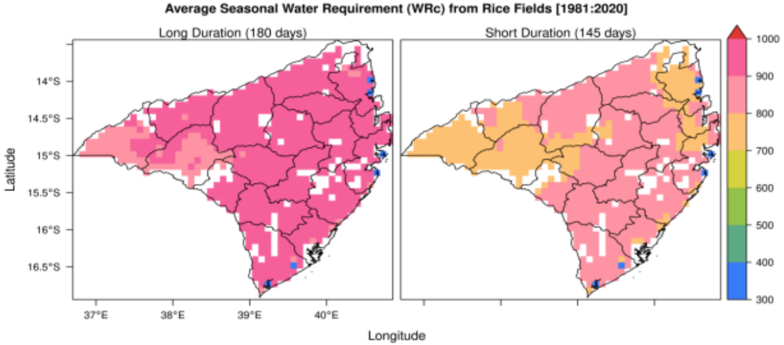
- ***Crop water requirement/Demand (WRc):*** refers to the amount of water that needs to be supplied.
- ***Crop coefficient (Kc)*** incorporates crop characteristics and averaged effects of evaporation from the soil.

WRc = Kc * ETo





Growth Stages	Initial Stage	Development Stage	Mid-season Stage	Late-season Stage	Total/Maximum
Improved varieties (Long Duration)					
Duration (Days)	60	60	30	30	180
Crop Height (m)	0.3	0.5	0.8	1.25	1.25
Kc	1.05	1.2	1.2	0.8	
local varieties (Short Duration)					
Duration (Days)	40	40	35	30	145
Crop Height (m)	0.3	0.5	0.8	1.25	1.25
Kc	1.05	1.2	1.2	0.8	

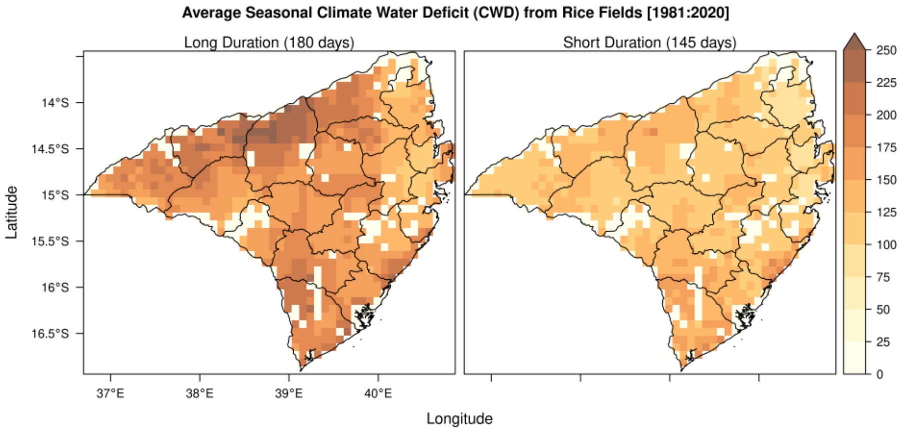


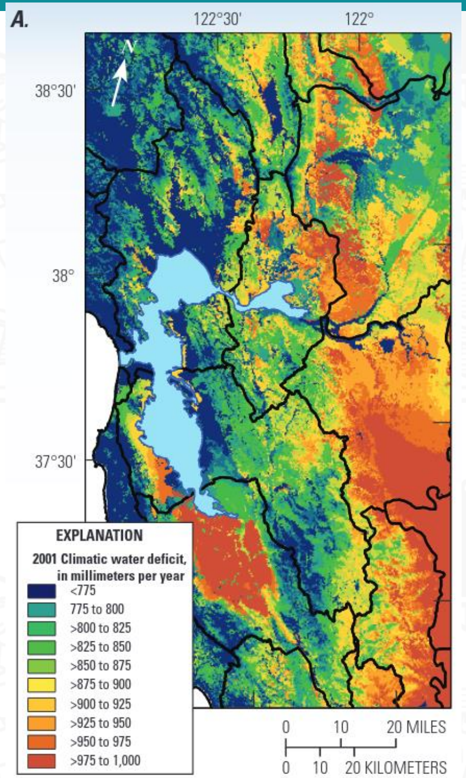
European Environment Agency (EEA)

Soil Water Balance Models: *applications*

To explore water-management options:

- ***Climatic Water Deficit (CWD):*** The difference between the potential evapotranspiration and the actual evapotranspiration. It is the amount of water plants would use if it were available.



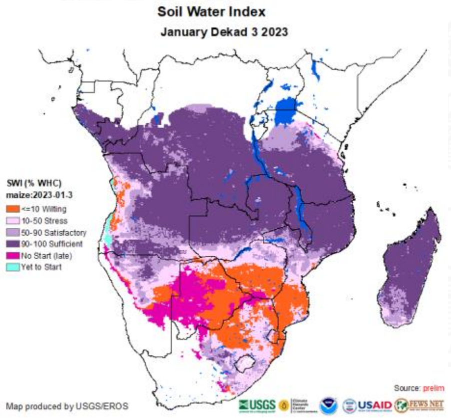


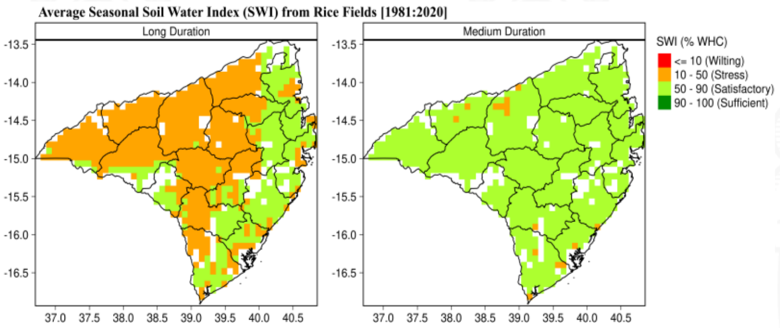
Soil Water Balance Models: *applications*

To monitor agricultural drought:

- ***Soil Water Index (SWI):*** The amount of water stored in the crop root depth as a percentage of the water holding capacity (WHC) of the soil.

Categories	Index (%)	Description
Sufficient	90 - 100	Enough soil water in the crop root zone to support the crop through the next few days without experiencing water stress.
satisfactory	50 - 90	Conditions ranging from some degree of stress to enough moisture to avoid crop stress in the next few days.
stress	10 - 50	The crop is likely to experience water stress (from severe to moderate) if there is no rainfall in the next few days.
wilting	0 - 10	The soil is already at very low moisture level such that continued drought may cause wilting of the crop.

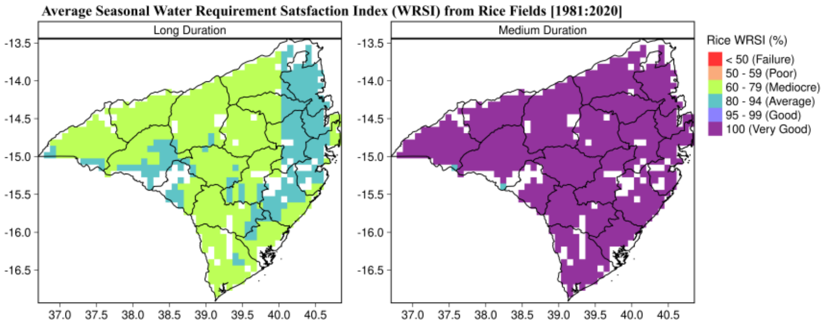


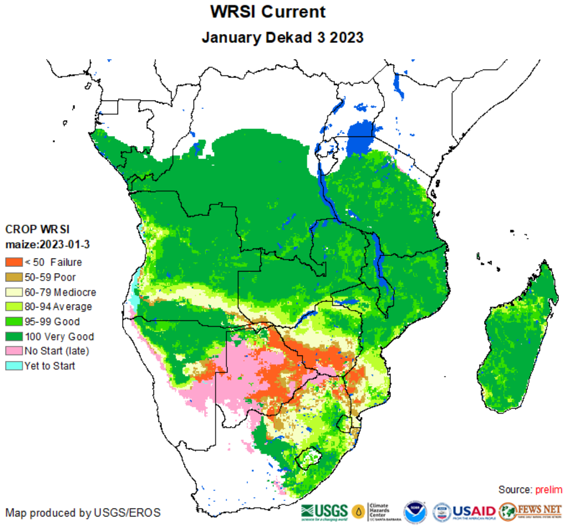


Soil Water Balance Models: *applications*

To monitor agricultural drought:

- ***Water Requirement Satisfaction Index (WRSI):*** the percentage of total seasonal crop water requirement satisfied by available soil moisture.



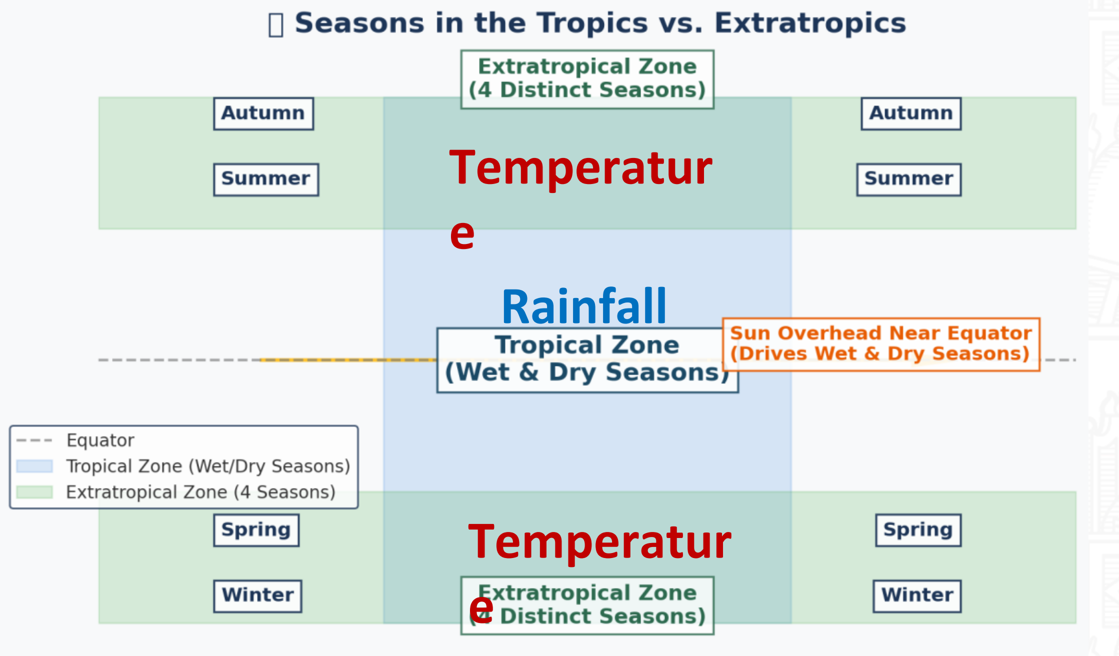


WRSI (%)	Condition
< 50	Failure
50 - 59	Poor
60 - 79	Mediocre
80 - 94	Average
95 - 99	Good
100	Very Good

An indicator of crop performance based on the availability of water to the crop during a growing season. FAO studies have shown that WRSI can be related to crop production using a linear yield-reduction function specific to a crop (FAO, 1977; FAO, 1986).

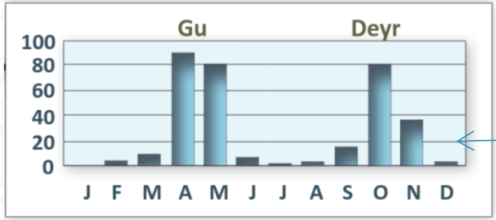
Characterizing the Wet Season Calendar: *rainfall seasonality*

- Season is a division of the year based on unique weather conditions.
- Generally, the season lasts ***at least a month.***
- for tropical climates, a wet season month is defined as a month where average precipitation is ***60 millimeters*** or more.

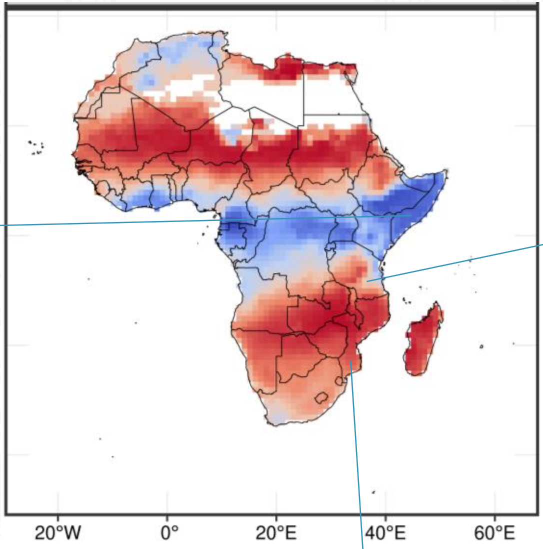


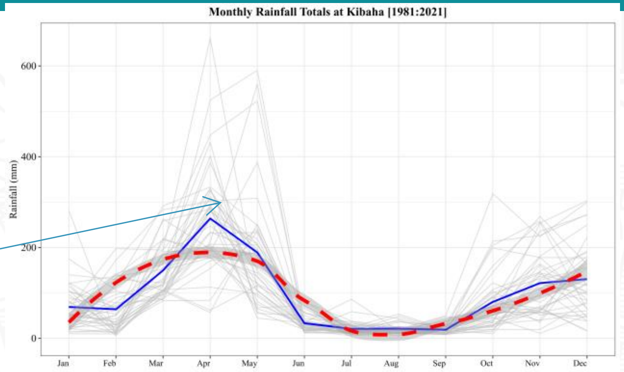
Characterizing the Wet Season Calendar: *rainfall seasonality*

Rainfall Seasonality ?



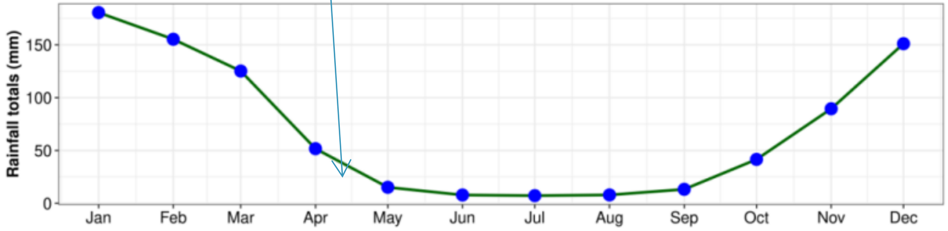
Bimodal





Quasi-bimodal

Unimodal



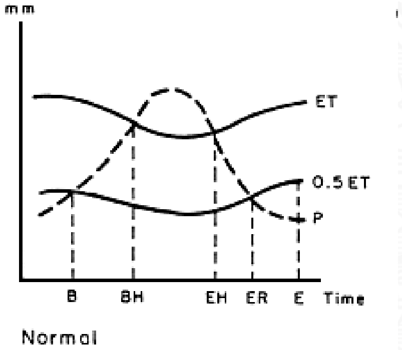
Characterizing the Wet Season Calendar: *rainfall seasonality*

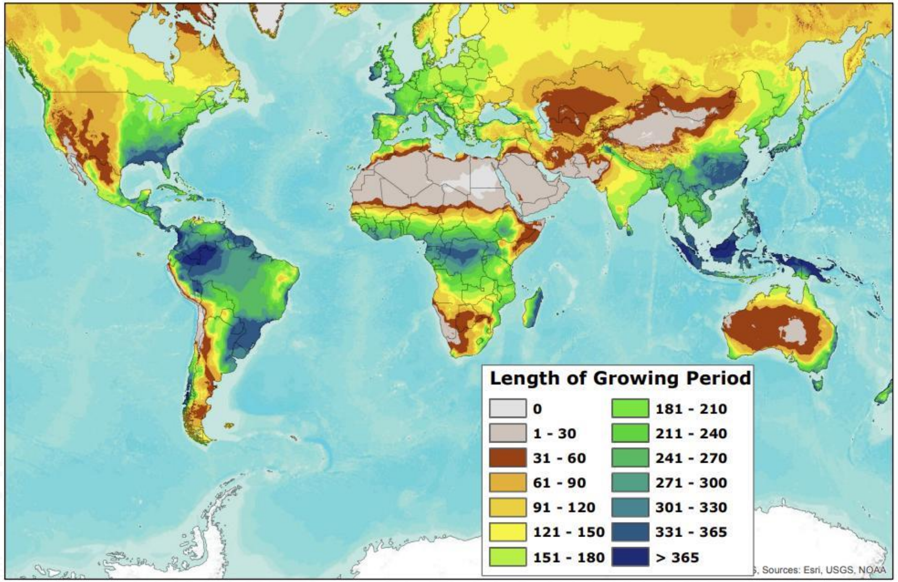
- Components;
  - Onset,
  - Cessation and
  - duration.
- The components defined either climatological point of view based on first rains and the agroclimatic/agronomic one which considers crop suitability.

- Climatological: the onset/cessation of the wet season has been either considered as the start/end of the rainy period, and hence was identified based on rainfall data.
- When the rain passes a certain threshold the season will start/end.
- The agroclimatic/agronomic defines based on soil moisture availability using water balance parameters.

Characterizing the Wet Season Calendar: *growing season*

- A growing season is the period of the year when crops and other plants grow successfully.
- Most crops need a growing season of at least 90 days.
- The Length of Growing Period (LGP) refers to the average duration when moisture availability allows crop growth.





Characterizing the Wet Season Calendar

The onset and cessation dates of the wet season are defined using agro-climatic approaches:

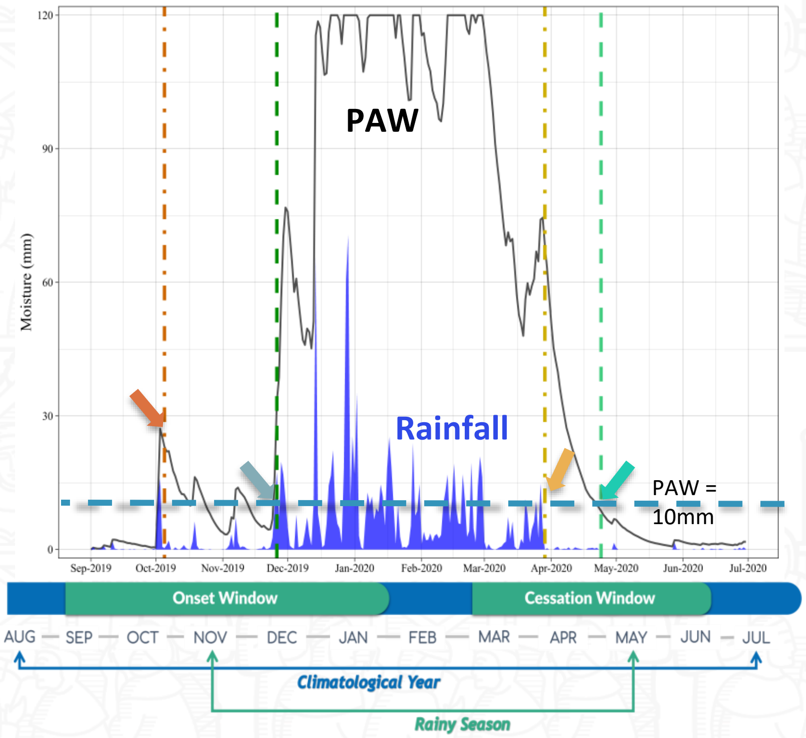
AgroClimatic Onset

The first day after 01-Sep, when the Eratio (Ea/Ep) > 0.5, followed by a 20-day period in which TAW remains > 10mm.

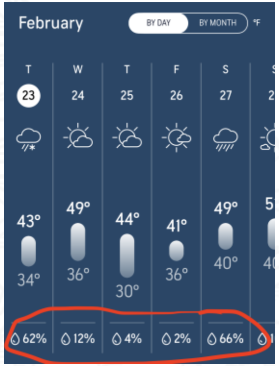
AgroClimatic Cessation

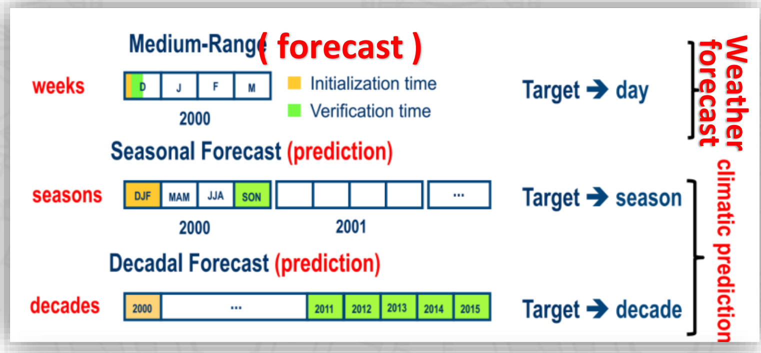
Season has ended at the first day (Eratio<=0.5) after 01-Mar following 12 consecutive non-growing days (PAW<10mm).

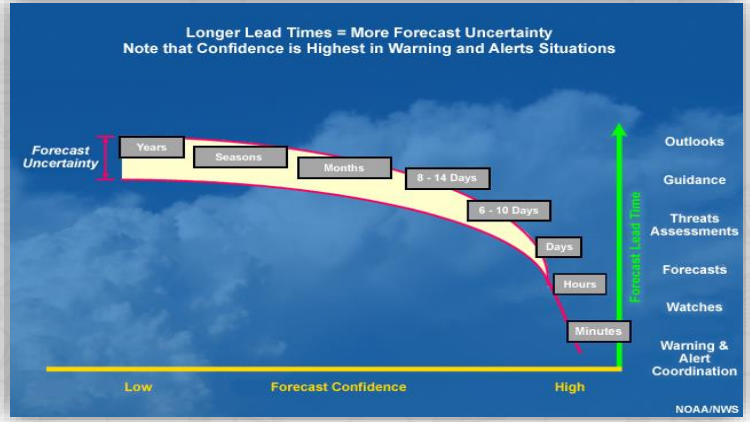
Remark: *The Total Plant Available Water (PAW) over the Effective Rootable Zone Depth (ERZD) of the soil shall remain greater than 10 mm, which ensures sufficient soil moisture for crop establishment and development over the growing period.*



Predicting Agronomic Onset of the Growing Season: *forecasts*







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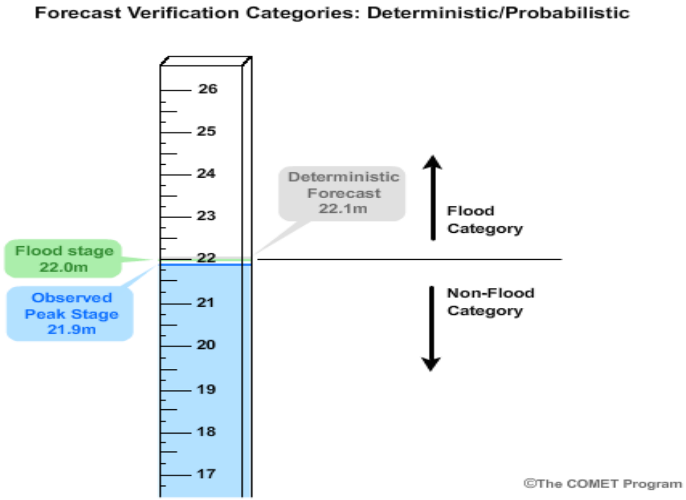
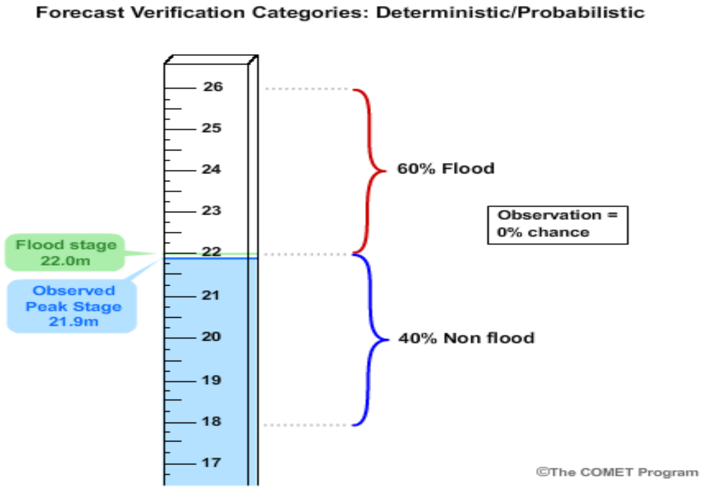
Predicting Agronomic Onset of the Growing Season: *forecasts*

Deterministic forecasts are single-value predictions with **no information about uncertainty** in that single value.



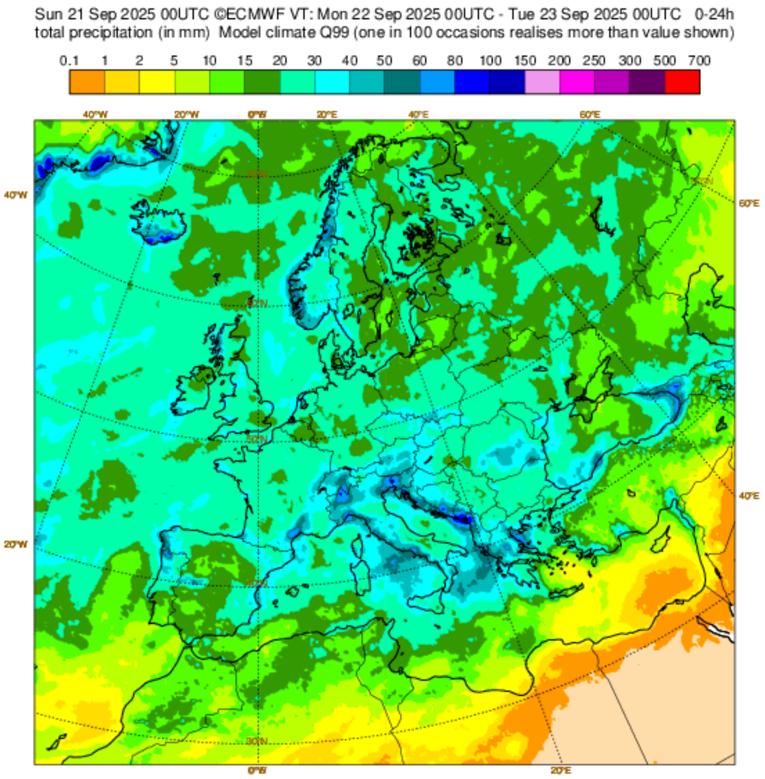


Probabilistic forecasts consist of multiple values or probabilities describing the range of possible outcomes.

Predicting Agronomic Onset of the Growing Season: *forecasts*

- Forecasts of an event of **a specific magnitude at a specific time and place**.
- These forecasts can be generated by **statistical or dynamical methods**, or a combination of these.
- Numerical Weather Prediction (NWP) generally consist of **deterministic forecasts of continuous variables**.

Example: *the most likely estimate of total rainfall in January is* ***150 mm***.



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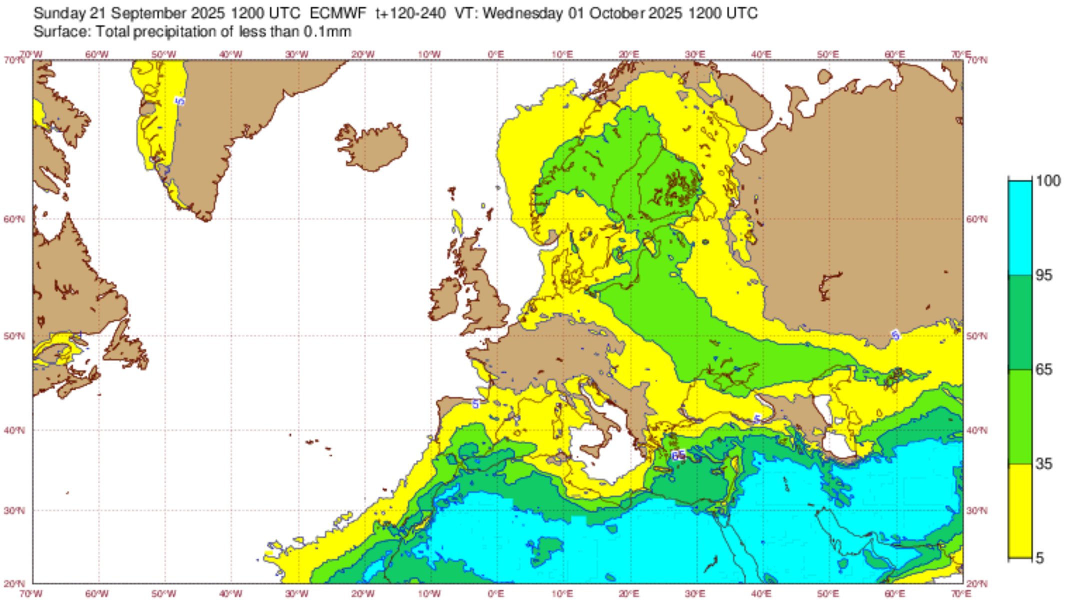
Predicting Agronomic Onset of the Growing Season: *forecasts*

- In order to deal ***quantitatively with uncertainty***, it is necessary to employ the tools of probability, which is the mathematical language of uncertainty.
- A probability statement always estimates the likelihood of occurrence of a specific event,



Example: *There is a 67% likelihood that the rainfall will fall between 200 and 700 mm.*

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Predicting Agronomic Onset of the Growing Season: *PoP*

Probabilistic of Precipitation (PoP): - describes the chance of measurable precipitation occurring at a point in the forecast area over a certain period of time.

$$PoP = P_a * P_c$$

Where: P_a is the **probability that precipitation will occur** somewhere in the forecast area during the forecast period.

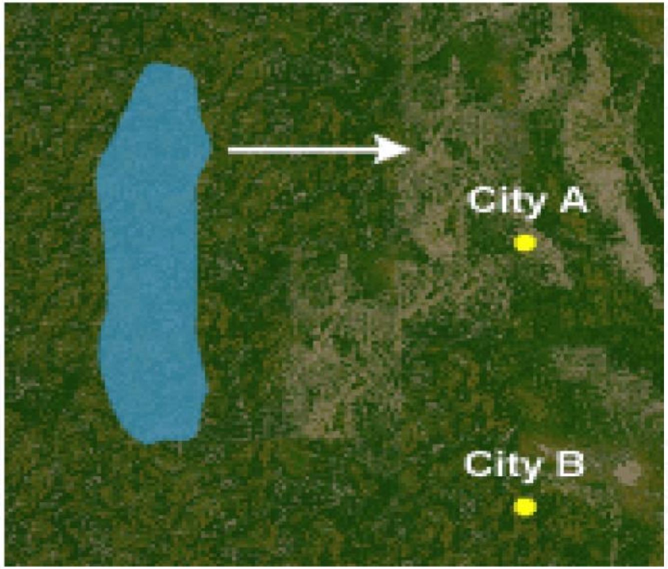
P_c is the **percent of the area that will receive measurable precipitation**, if it does occur.

Example: If a meteorologist is 80% confident that there will be rain in 50% of the forecast area, PoP is 80% * 50% = 40%

Predicting Agronomic Onset of the Growing Season: *PoP*

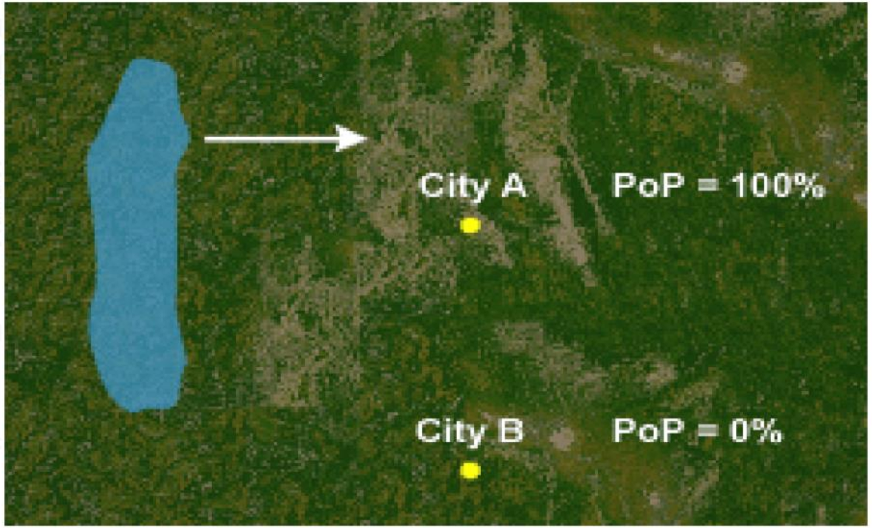
Question:

If it is **100% probable** that a line of thunderstorms will bring precipitation to the northern **80% of a forecast area**, what is the PoP for the entire forecast area and what is the PoP for a city in the southern part of the area where NO precipitation is expected?



Predicting Agronomic Onset of the Growing Season: *PoP*

Answer: The PoP for the forecast area would be 80% (1.00 x .80 = 80%). In this example, the line of thunderstorms (blue area) is expected to travel over City A, but miss City B. The PoP for City B would be 0%. If all of City A is certain to get rain from the storms, it would have a PoP of 100%.



Predicting Agronomic Onset of the Growing Season: *likelihood*

Likelihood: - Likelihood is often described in **terms of frequency**, derived from observation or model analysis; it refers to **how often** a certain event may occur.

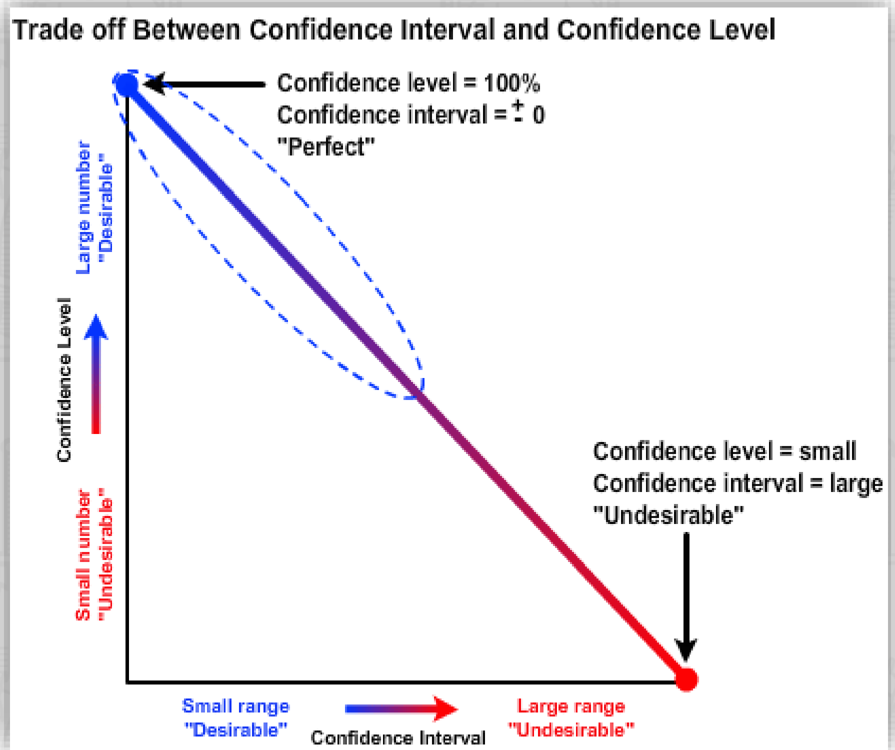
Example: *If the probability of an event occurring is 10%, this means that the event will only occur on one occasion in every 10 (or equivalent 10 in 100). Therefore, on the other nine out of 10 occasions the event will not occur.*

Terminology	Likelihood of the Occurrence
Virtually Certain	> 99% Probability
Very Likely	> 90% Probability
Likely	> 66% Probability
As Likely as Not	33% - 66% Probability
Unlikely	<33% Probability
Very Unlikely	<10% Probability
Exceptionally Unlikely	< 1% Probability

Predicting Agronomic Onset of the Growing Season: *Confidence Interval*

- Confidence Level: prescribed probability with the confidence interval.
- Confidence Interval: range of values that includes the true value. These help with **expressing forecast uncertainty**.

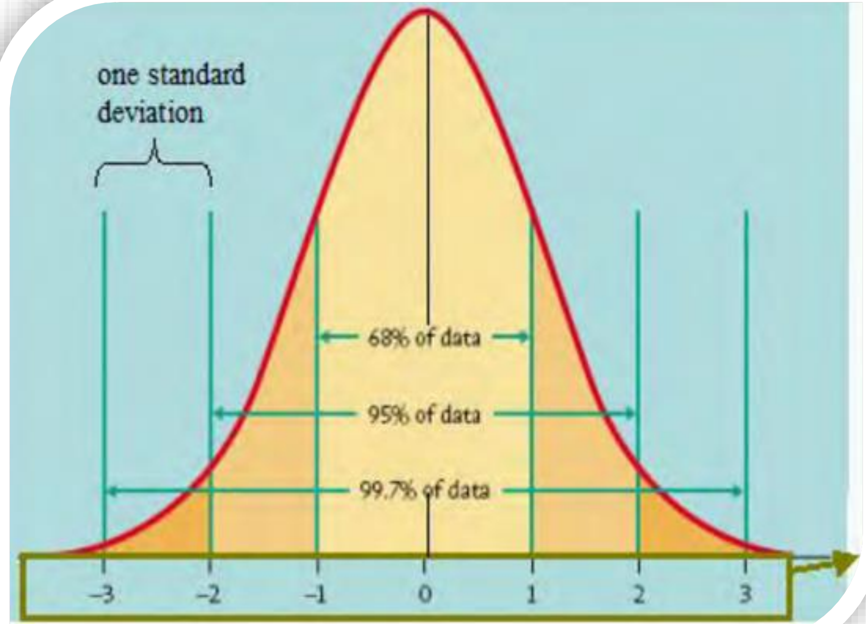
Example: *So a forecast may read, "there is a 95% chance that the annual rainfall total will be* ***20-3000 mm****". The confidence interval is the range of values, 20-3000, and the confidence level is 95%.*



Predicting Agronomic Onset of the Growing Season: *tercile probability*

Tercile forecasts divide historical climate data into three equal categories:

- Below-normal
- Near-normal
- Above-normal



- The lower tercile, which is the value below which the outcome occurs in 1 out of 3 cases in the model climate, assuming a stationary climate. i.e. $X_{lower} = X_{median} - 1.43 * X_{std}$.

- The upper tercile, which is the value above which the outcome occurs in 1 out of 3 cases in the model climate, assuming a stationary climate. i.e. $X_{upper} = X_{median} + 1.43 * X_{std}$.

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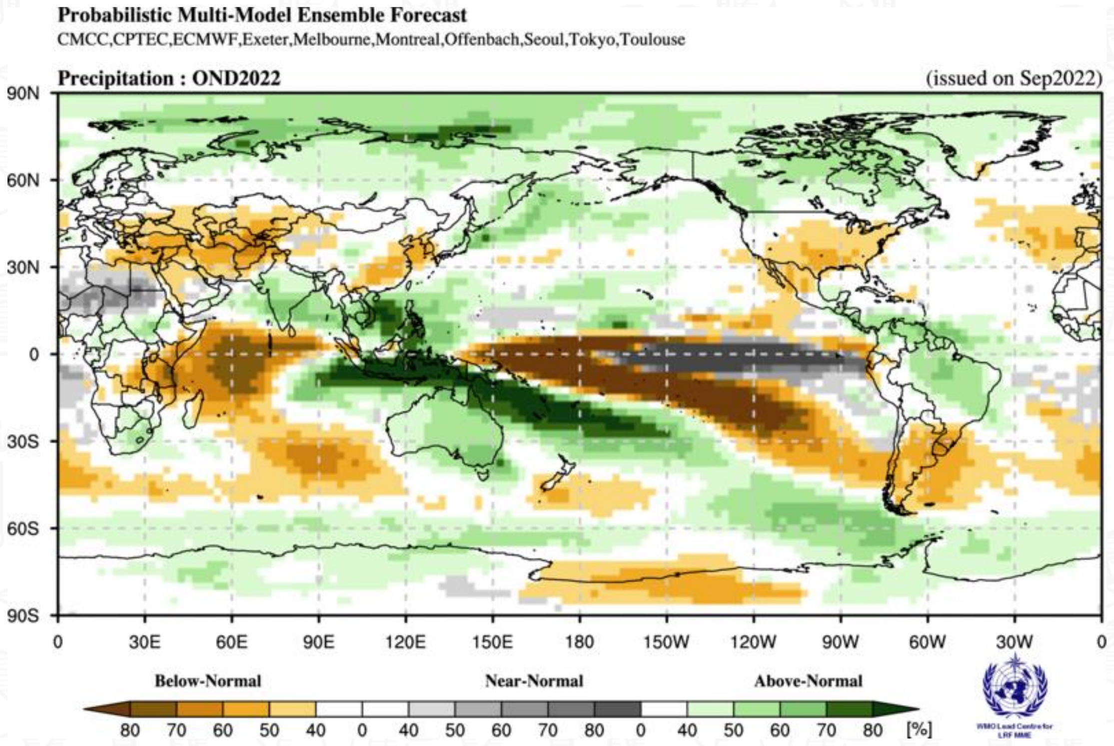
Predicting Agronomic Onset of the Growing Season: *Tercile Forecasts*

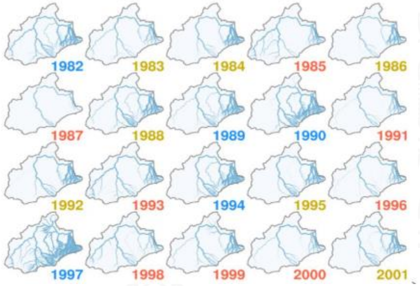
- Seasonal forecasts express the probability that upcoming conditions will fall into one of these categories.

- Helps in understanding shifts in rainfall or temperature likelihoods compared to the historical average.



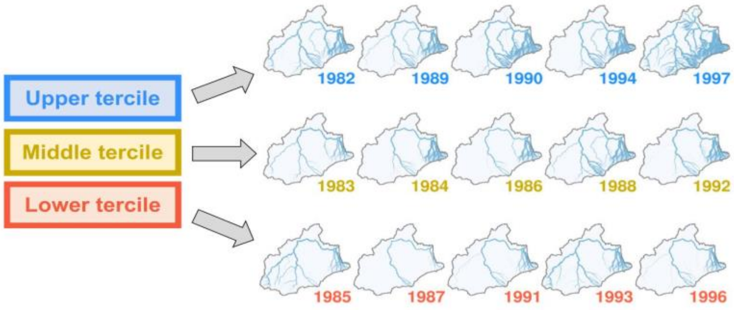
Predicting Agronomic Onset of the Growing Season: *in AquaBEHER*

I. Estimating historical WSC outcomes using AquaBEHER

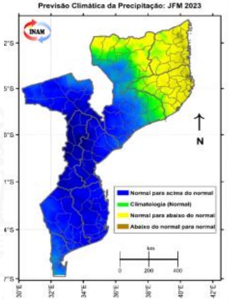


Lables colored according to tercile cataqories

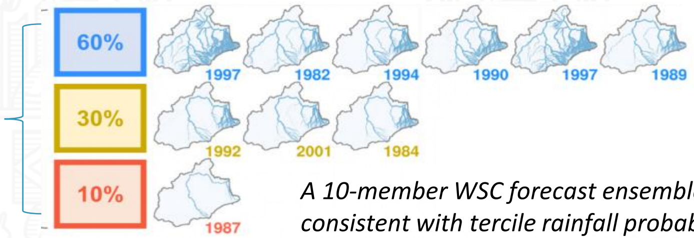
II. Define the quantile



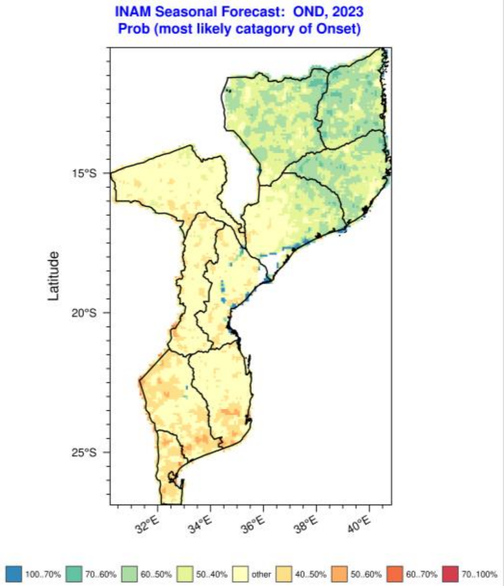
Tercile probabilities of seasonal rainfal from NMHS



III. Generate WSC forecast ensembles



A 10-member WSC forecast ensembles consistent with tercile rainfall probabilites: generated by resampling with replacement



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Agricultural Meteorology and Climate Services: from weather impacts to integrated climate-crop modelling

Using AquaBEHER Seasonal Forecast for Planting Decisions

Case Study

Objective:

Learn how to use AquaBEHER with daily weather data to estimate the onset of the wet season and make informed planting decisions.

Background:

Farmers often face uncertainty about when to plant crops, especially in rainfed systems. Planting too early risks seed loss if rains stop; planting too late reduces the length of the growing season. Seasonal forecasts help reduce these risks by predicting the likely onset of the wet season.

In this exercise, you will apply AquaBEHER tools to analyze weather data and simulate a seasonal forecast for crop planting decisions.

Using AquaBEHER Seasonal Forecast for Planting Decisions

Case Study

Steps to Follow:

- Estimate Daily Evapotranspiration (ET):
  - Use AquaBEHER functions to calculate reference evapotranspiration.
  - Understand how ET reflects atmospheric water demand.
- Calculate Soil Water Balance Parameters:
  - Derive soil moisture storage and deficit.
  - Track how rainfall and ET affect soil water availability.
- Estimate Historical Wet Season Characteristics (WSC):
  - Identify the average onset, cessation, and length of the wet season from historical data.
  - Compare variability across years.

Case Study

Using AquaBEHER Seasonal Forecast for Planting Decisions

Steps to Follow:

- Generate Seasonal Forecast of Wet Season Onset:
  - Use AquaBEHER to simulate the onset for the current year based on forecast data.
  - Interpret the probability of early, normal, or late onset.
- Make Planting Decisions:
  - Based on the forecasted onset, recommend the best planting window.
  - Discuss potential risks and backup strategies (e.g., staggered planting, drought-tolerant varieties).

Expected Output:

- ✓ Tables/graphs showing ET, water balance, and wet season onset.
- ✓ A short written recommendation.

Thankyou

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