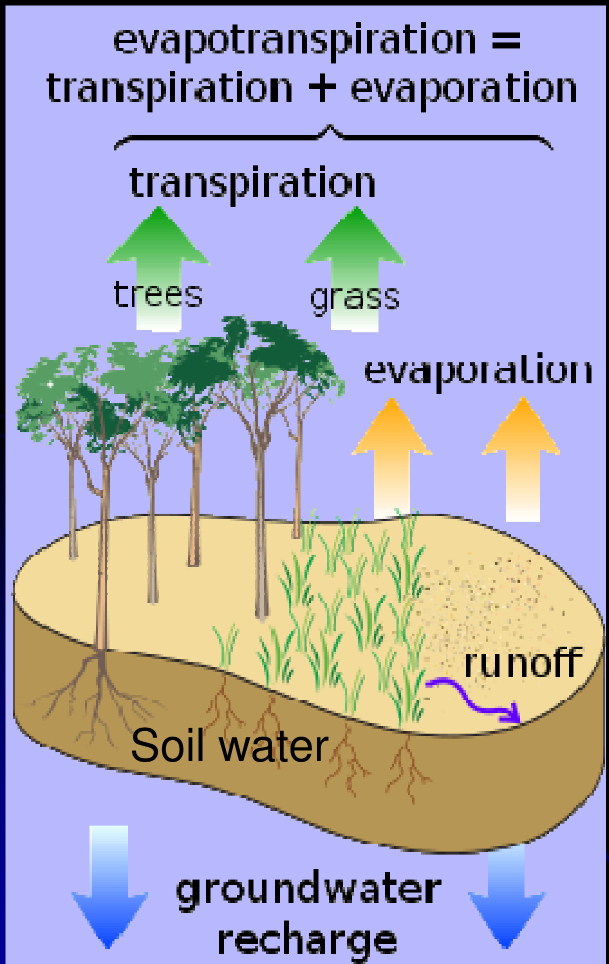
WMO/UNISDR Expert Group Meeting on Agricultural Drought Index

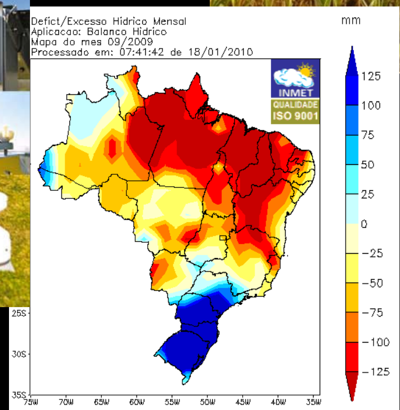
Murcia, Spain – 02 to 04 June 2010

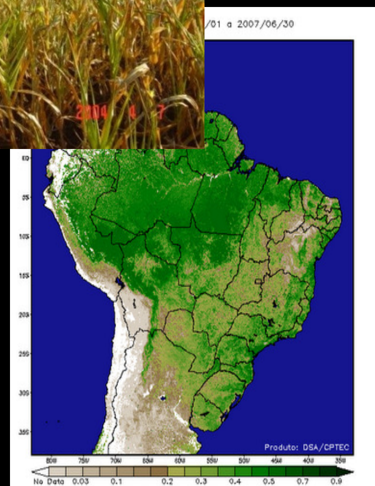
Water Balance Models

Tools for Integration



Prof. Paulo C. Sentelhas
ESALQ - University of São Paulo



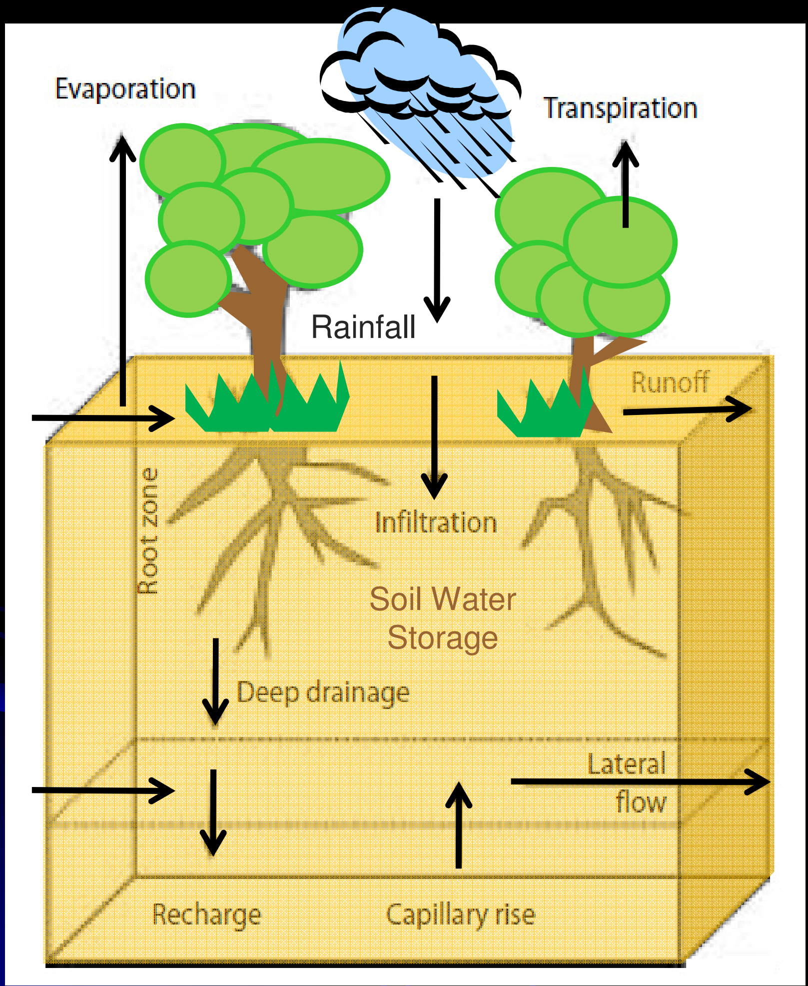


Water Balance Models
Tools for Integration

Presentation Outline

- The Water Balance Basic Concepts
- Water Balance Models in Current Use in Different Countries
- Water Balance as a Tool for Agric. Drought Monitoring
- Strengths, Weaknesses and Limitations of Water Balance Models for Drought Monitoring
- Final Remarks

The Water Balance Basic Concepts



WB is based on the Conservation of Mass, where:

E+T (ET) = Evapotranspiration

P = rainfall

Ro = Runoff

Lf = Lateral flow

Dd = Deep drainage

Cr = Capillary rise

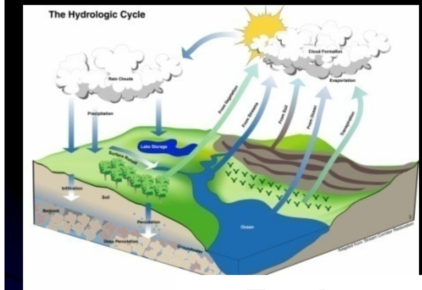
SWS = Soil water storage

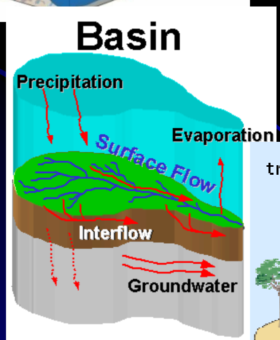
$$\pm \Delta SWS = P + Cr \pm Ro \pm Lf - ET - Dd$$

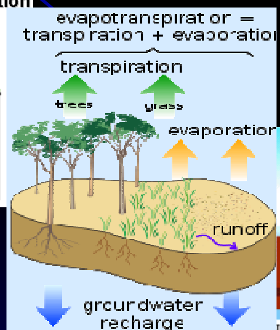
$$\pm\Delta SWS = P + Cr \pm Ro \pm Lf - ET - Dd$$

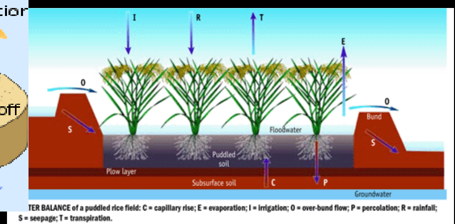
The WB equation above has a clear conceptual basis and seems simple in principal, but in practice it is difficult to measure or estimate each of the components

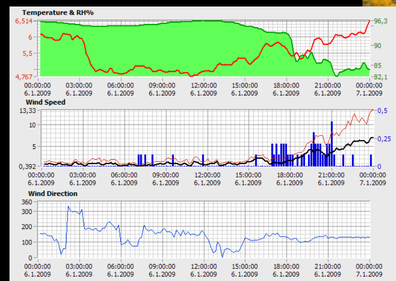
The complexity of the water balance model considered will require information about the system and the data available

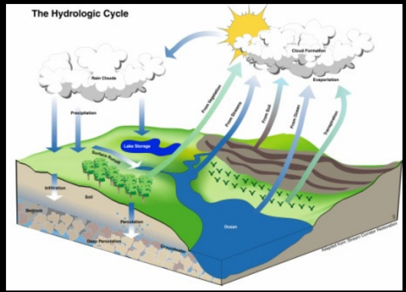


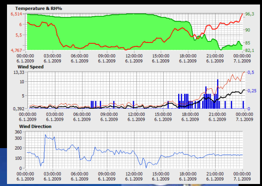


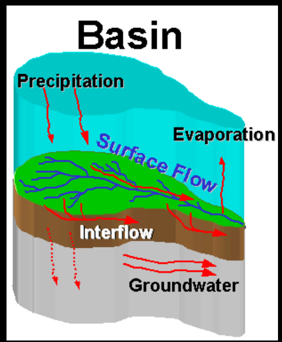


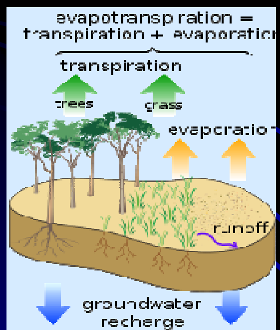


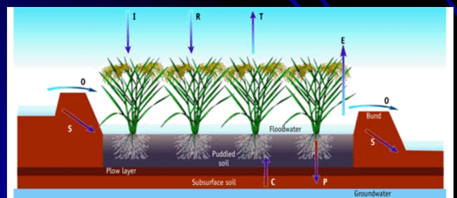












WATER BALANCE of a puddled rice field: C = capillary rise; E = evaporation; I = irrigation; O = over-bund flow; P = percolation; R = rainfall; S = seepage; T = transpiration.

Depending on the objective of the study and data availability, WB modeling can have different levels of complexity, although the model is a simplification of the real world, no matter how complex it may be

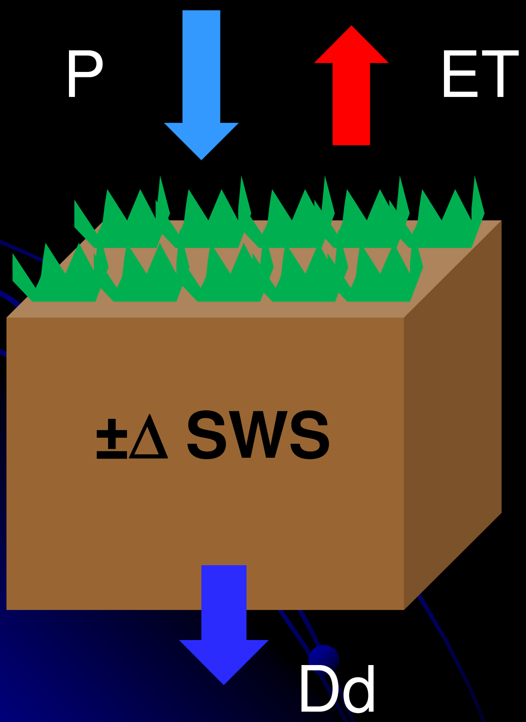
It is important to recognise that increasing model complexity does not necessarily improve accuracy

Simple model can be suitable for a region, since calibrated for that

Sometimes only more complex models can explain the process evaluated

Simple WB Models

They are basically based on the computation of rainfall and evapotranspiration for a control volume of soil



±ΔSWS = P– ET - Dd

Input data:

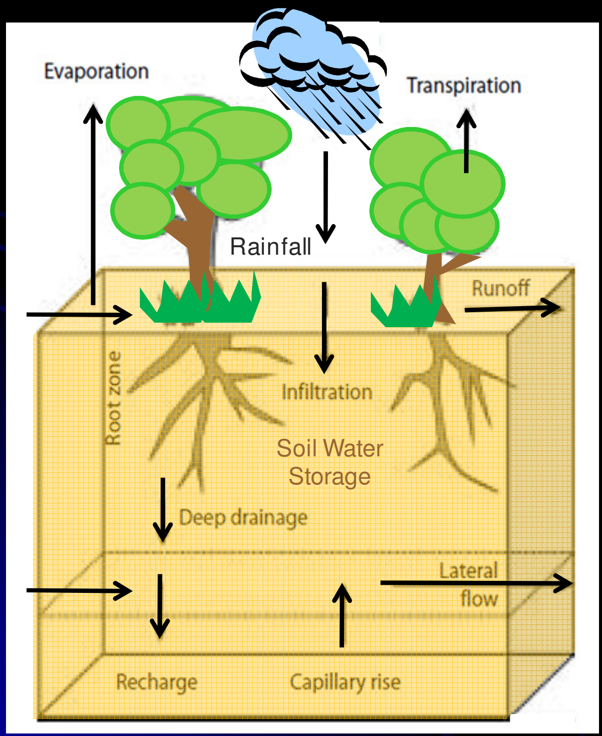
Rainfall (P)

Actual ET (ETa) = f (ETP)

Soil Water Holding Capacity (SWHC)

Complex WB Models

They deal with soil water dynamics as a function of the interaction among soil-plant-atmosphere systems



$$\pm\Delta SWS = P + Cr \pm Ro \pm Lf - ET - Dd$$

They require more data, mainly from soil perspective (hydrolical characteristics of the different layers). Crop information is also important for modeling water extraction

Matching model complexity with data availability

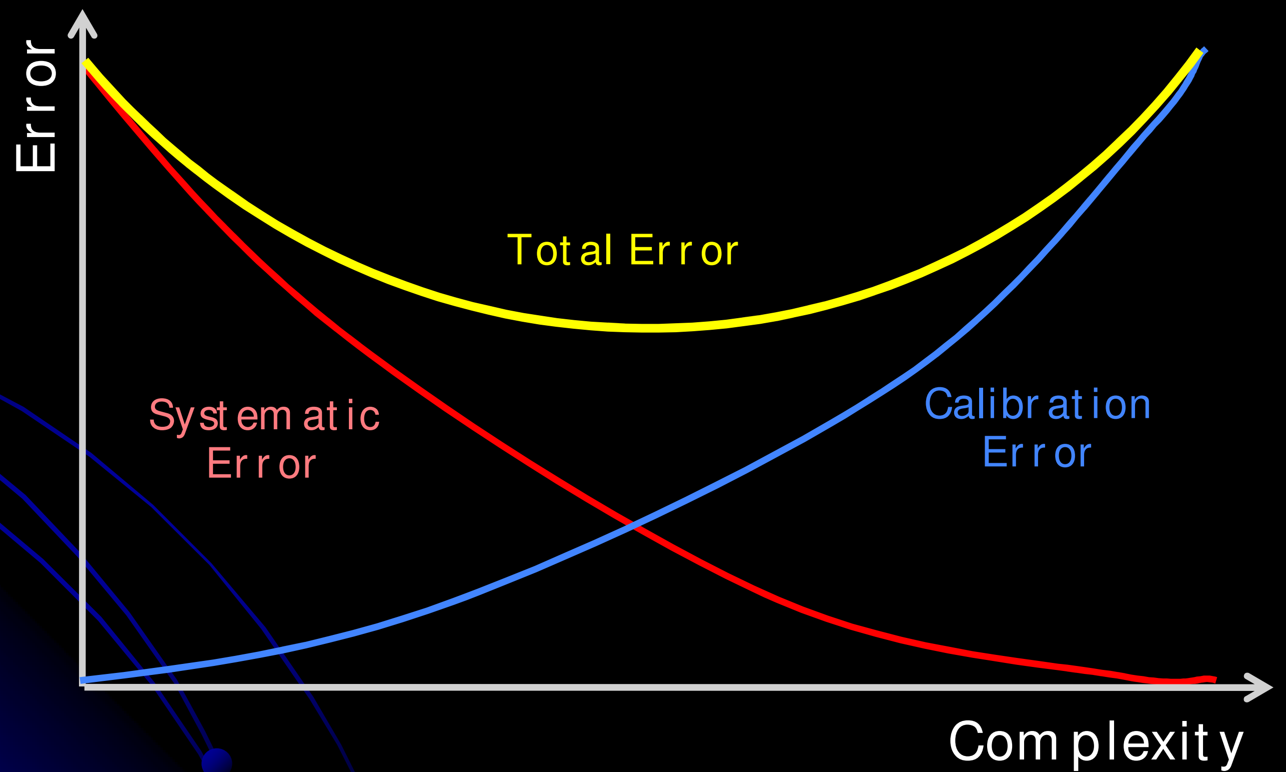
The main purpose of water balance modeling is to improve our understanding of the critical processes that influence soil water storage and, consequently, crop growth, development and yield

Users should avoid unnecessary complexity but at the same time choose the best option to achieve a level of process detail consistent with the importance of the process for the application in question

?

Simplicity X Complexity

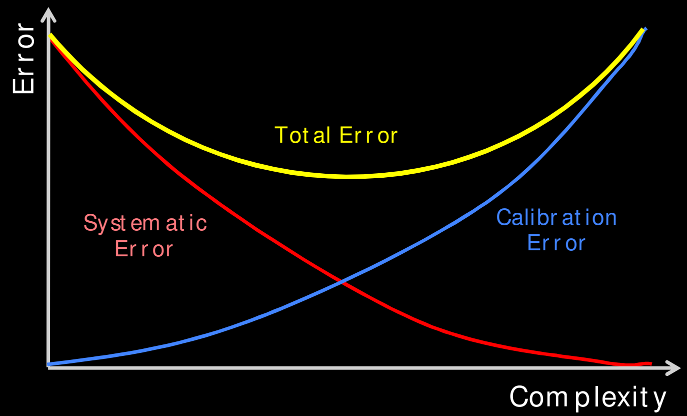
In achieving the balance between Simplicity and Complexity, users should be aware of two types of errors:



Adapted from Zhang et al. (2002)

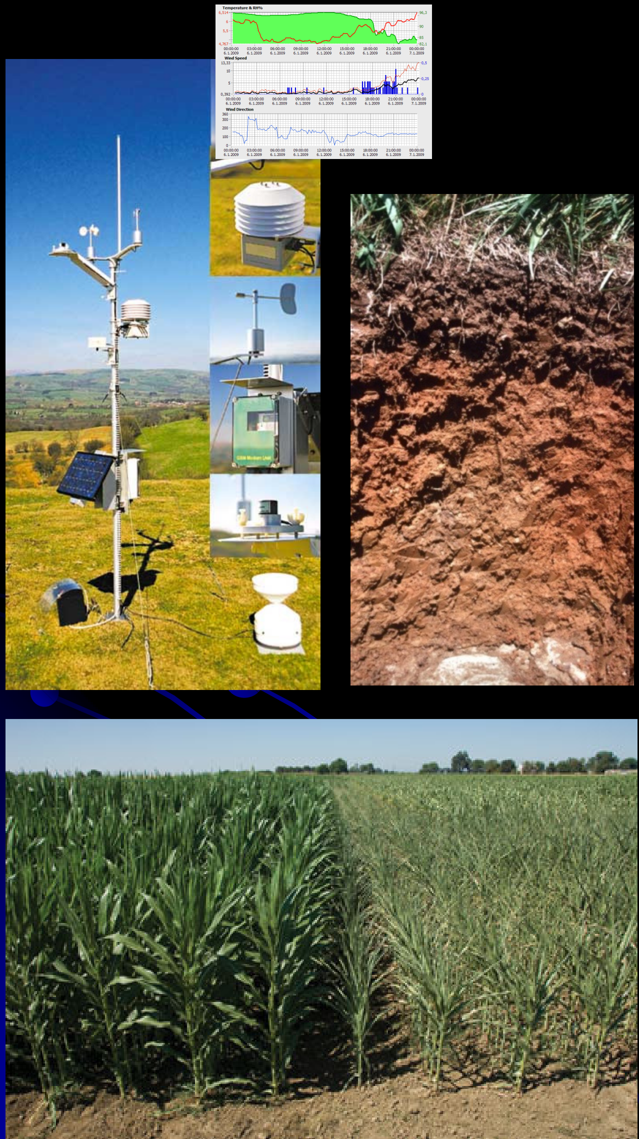
Simplicity X Complexity

Systematic Error – it results from simplifying assumptions in the WB model, for example not considering runoff. More complex the WB model smaller is the systematic error.



Calibration Error – it results from the lack of knowledge of the parameters that are needed for the WB model. More complex the WB model higher is the risk of parameterization errors.

Simplicity X Complexity



Availability of weather, soil, and plant data are crucial for choosing a WB model

Where limited data are available, the relatively simple WB model will be required

Where a complete dataset is available, complex WB models can be applied, since parameterized for that

A complex WB model can give as poor results as a simple WB model, if not properly calibrated for the specific conditions of interest

Water Balance Models in Current Use in Different Countries for Agricultural Drought Monitoring

There are several different ways to estimate the WB of a given region, catchment and crop

Simple WB Model

Climatological WB (T&M, 1955)

Most used by M&HSs in Brazil and South America

Complex WB Models

Hydrological WB

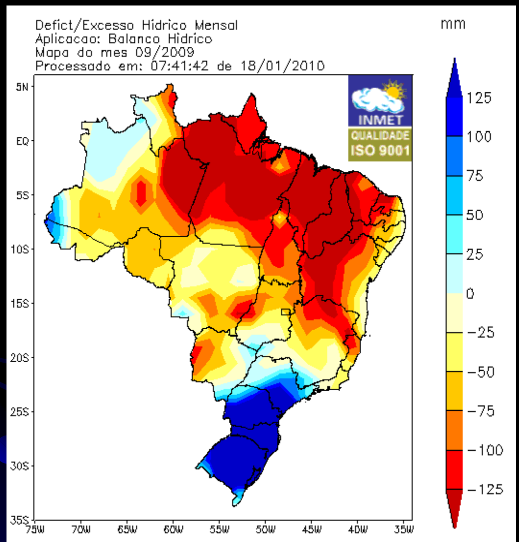
MUSAG WB

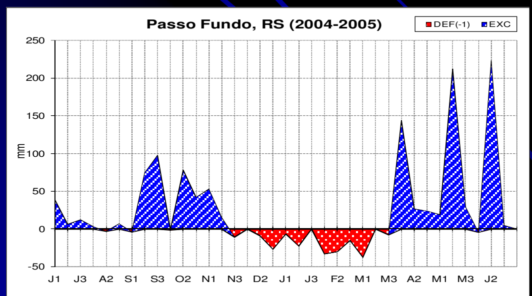
FAO56 WB

Ritchie WB (DSSAT)

Simple WB Model

Climatological WB (Thornthwaite & Mather, 1955)





Inputs

Rainfall,

ETP & SWHC

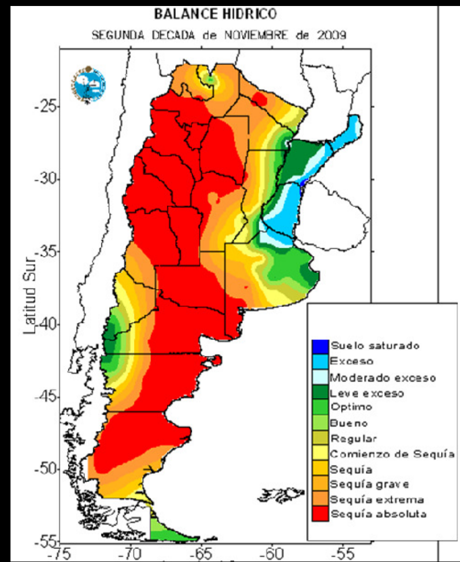
Outputs

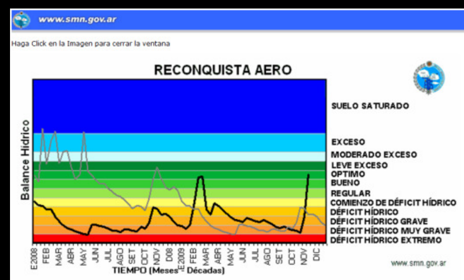
SWS

ΔSWS

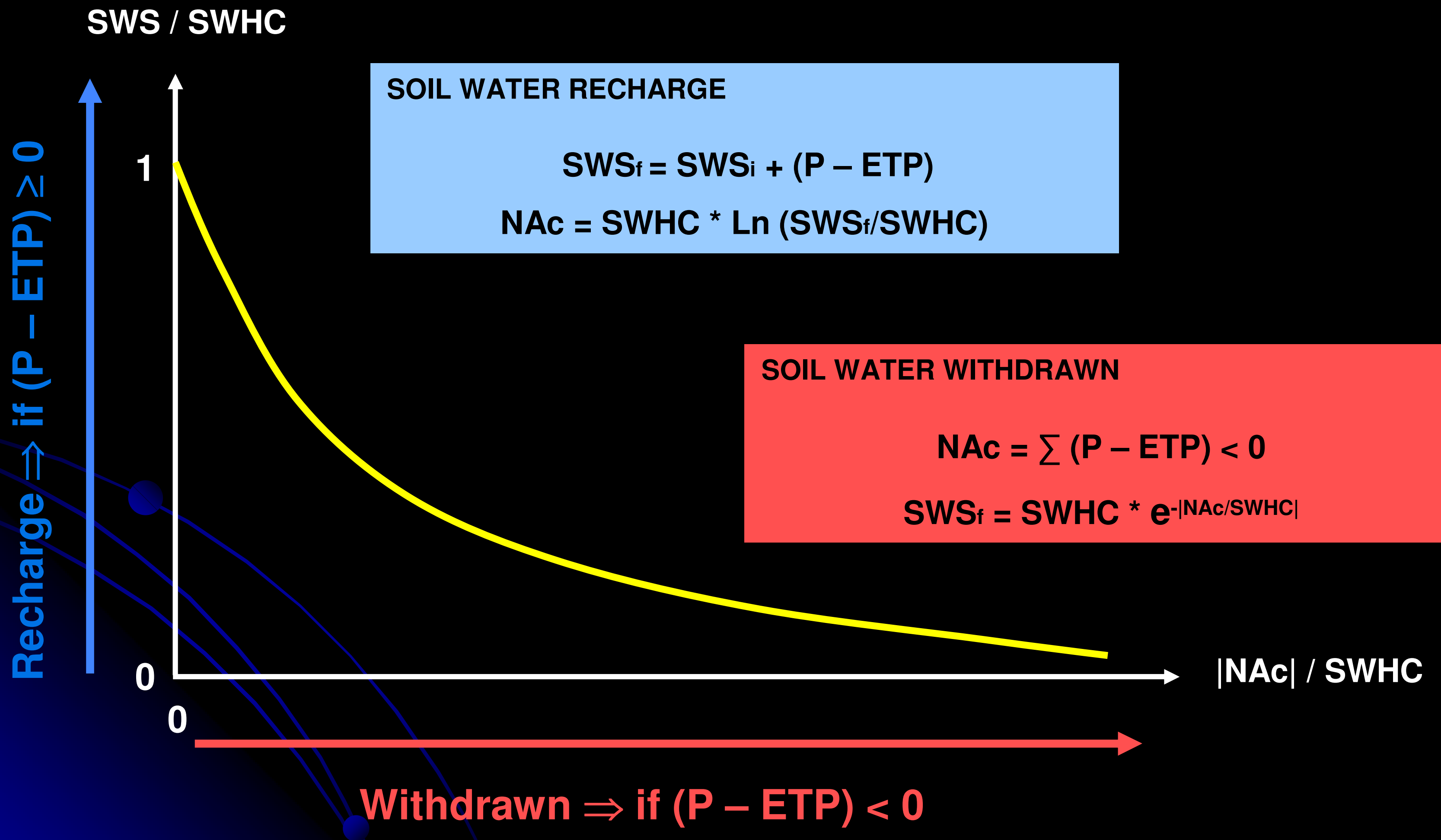
ETa

WD & WS





Climatological WB – Water Withdrawn and Recharge



SOIL WATER RECHARGE

$$SWS_f = SWS_i + (P - ETP)$$

$$NAc = SWHC * Ln (SWS_f / SWHC)$$

SOIL WATER WITHDRAWN

$$NAc = \sum (P - ETP) < 0$$

$$SWS_f = SWHC * e^{-|NAc/SWHC|}$$

Climatological WB – Other Calculations

$$\Delta SWS = SWS_f - SWS_i$$

$$\text{If } (P\text{-}ETP) \geq 0 \Rightarrow ETa = ETP$$

$$\text{If } (P\text{-}ETP) < 0 \Rightarrow ETa = P + |\Delta SWS|$$

$$DEF = ETP - ETa$$

$$\text{If } SWS < SWHC \Rightarrow WD = 0$$

$$\text{If } SWS = SWHC \Rightarrow WS = (P\text{-}ETP) - \Delta SWS$$

Time Scale

Daily to Monthly

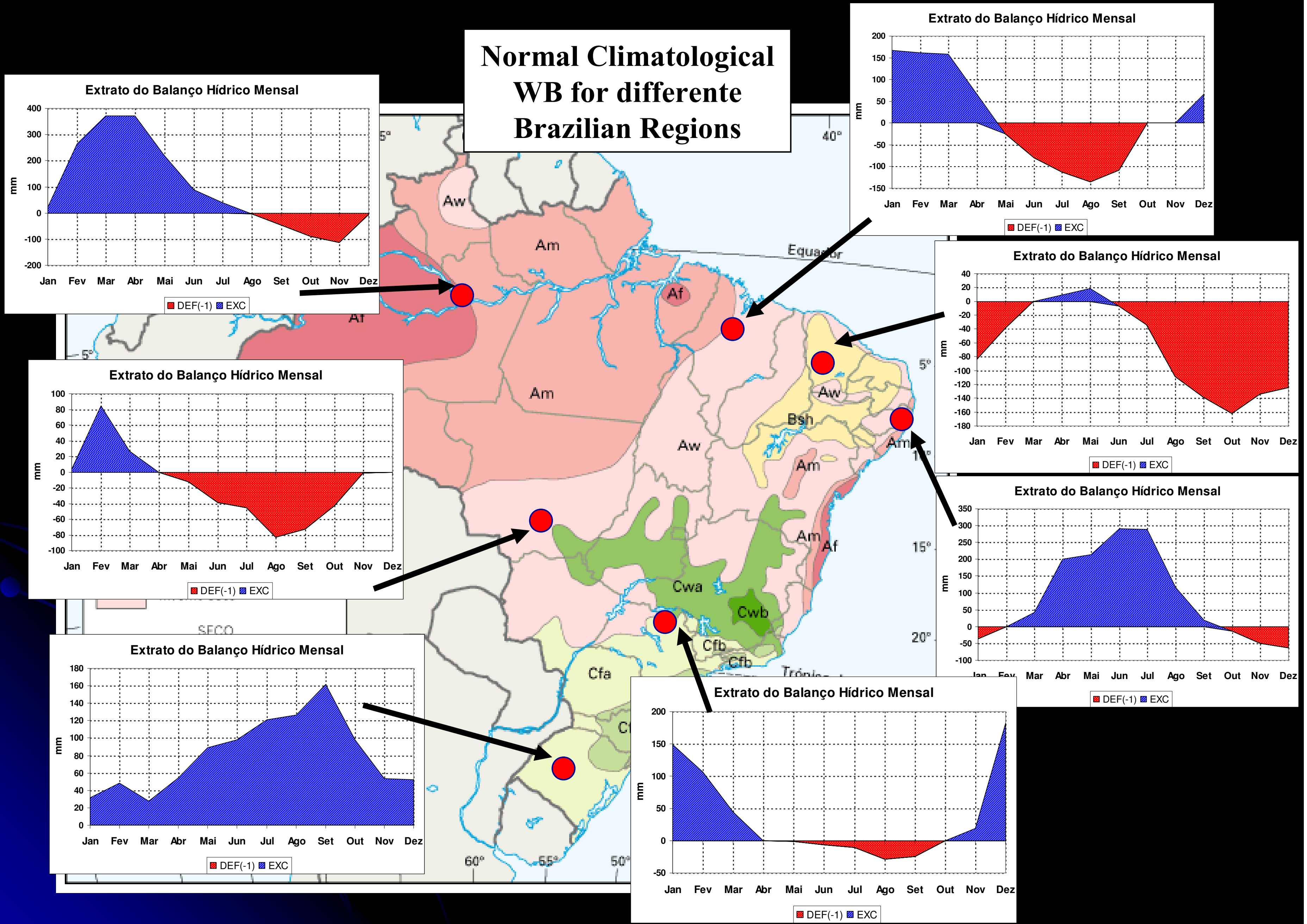
SWHC

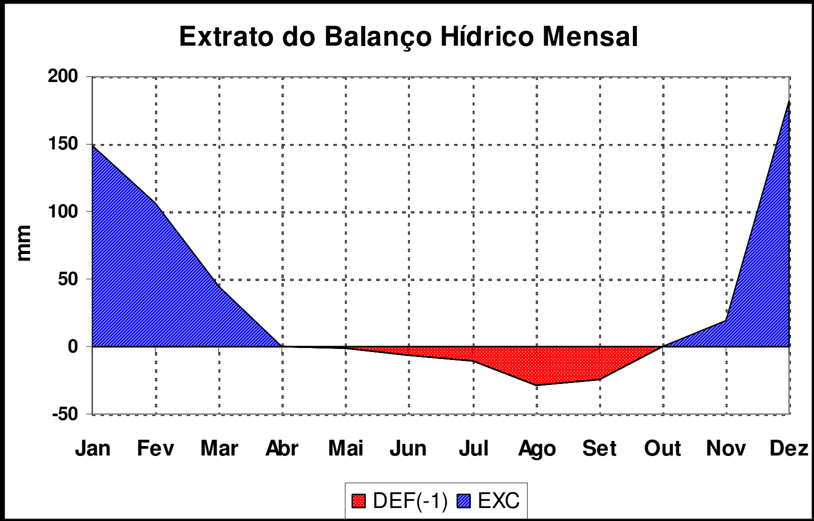
Normally from 25 to 200 mm, depending of the purpose

ETP Method

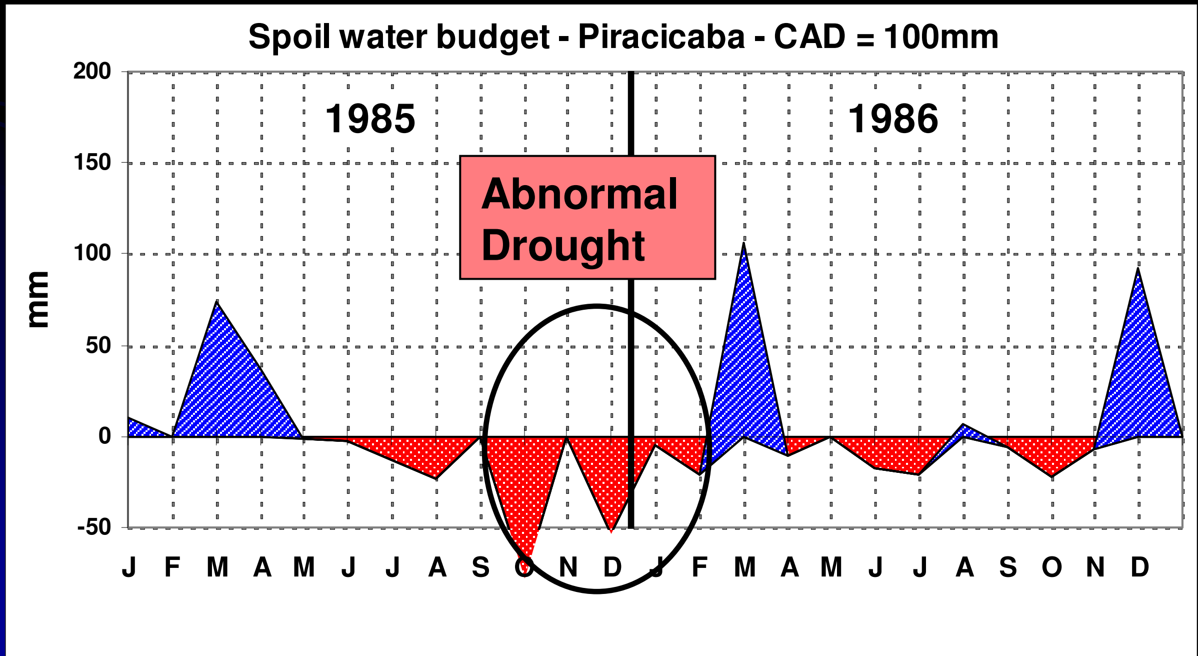
Anyone, since calibrated locally. Depends on data availability

Normal Climatological WB for differente Brazilian Regions

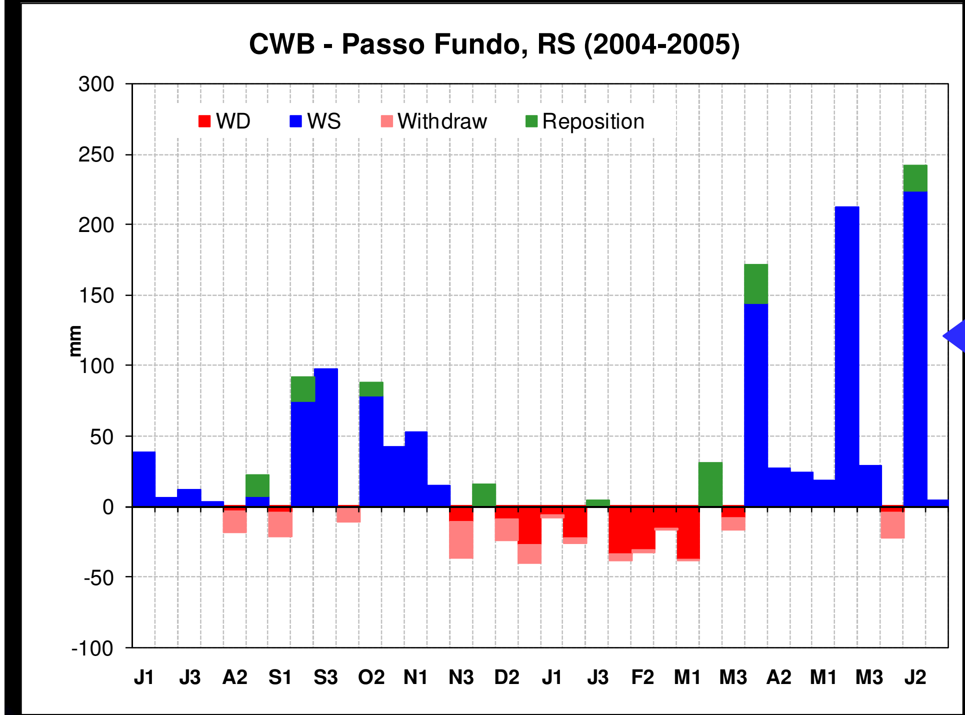




Monthly Normal Climatological WB
Piracicaba (1961-1990)

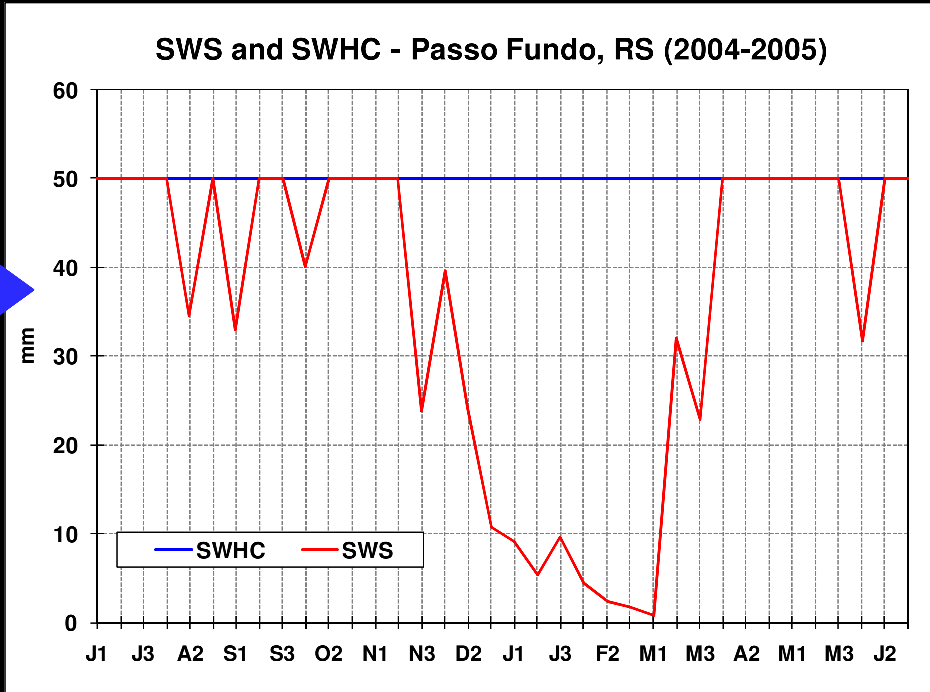


10-day Serial Climatological WB
Piracicaba (1985-86)



WS, WD, ±ΔSWS

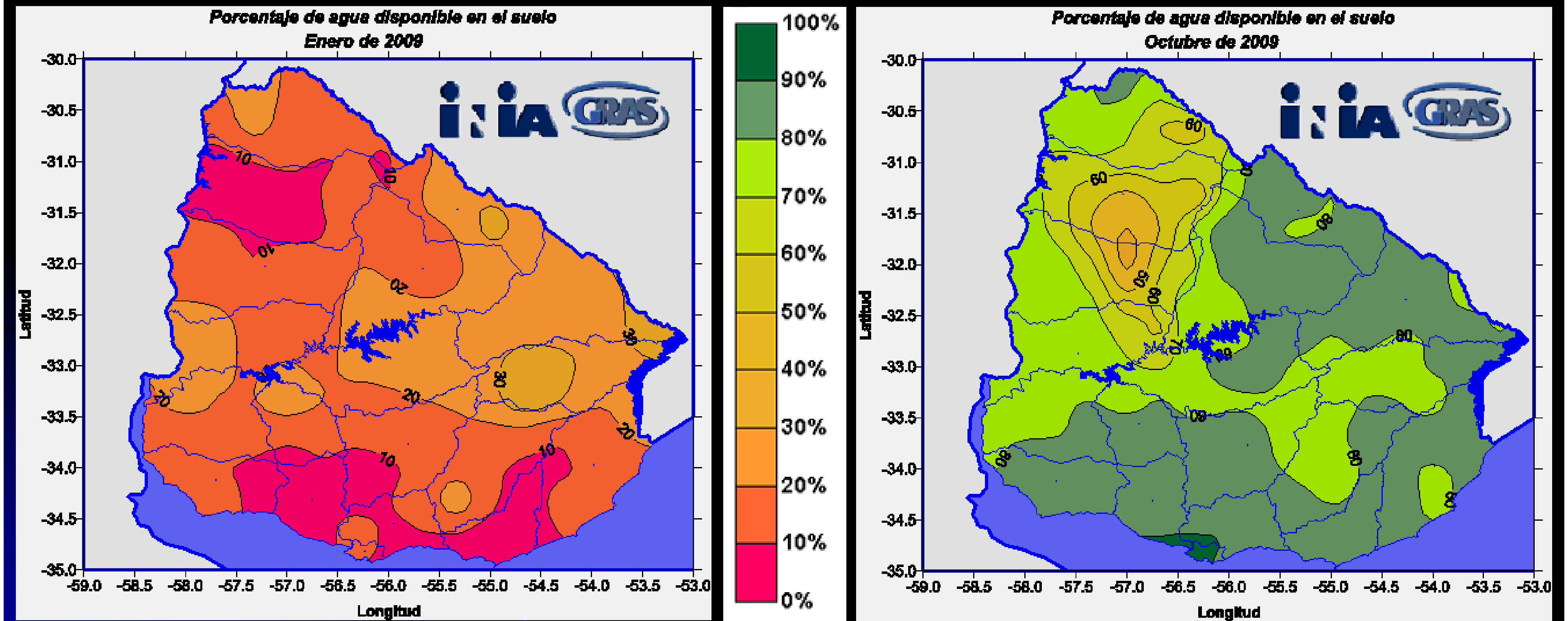
SWS



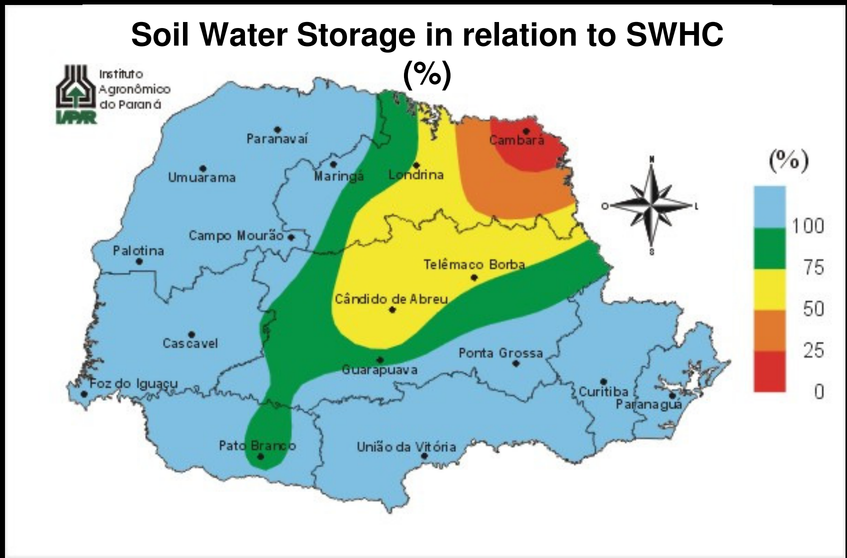
Climatological Water Balance Monitoring - Uruguay

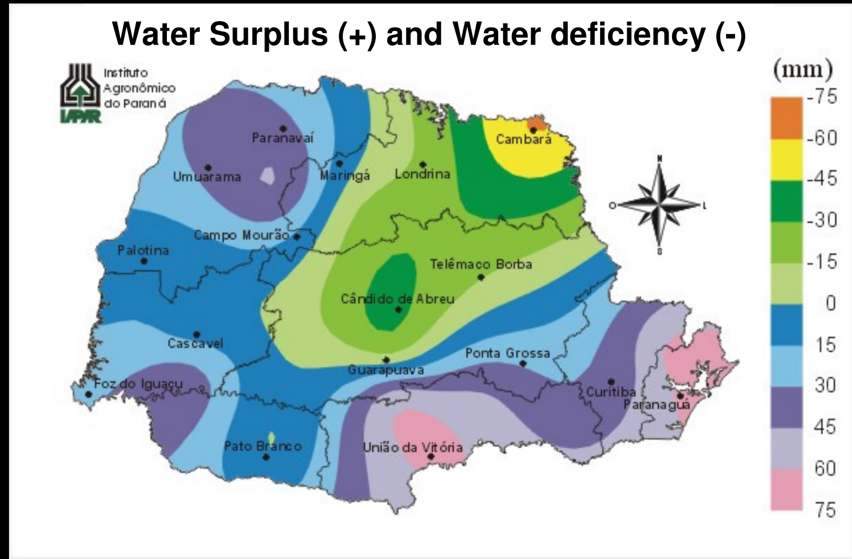
% of Soil Available Water
January 2009

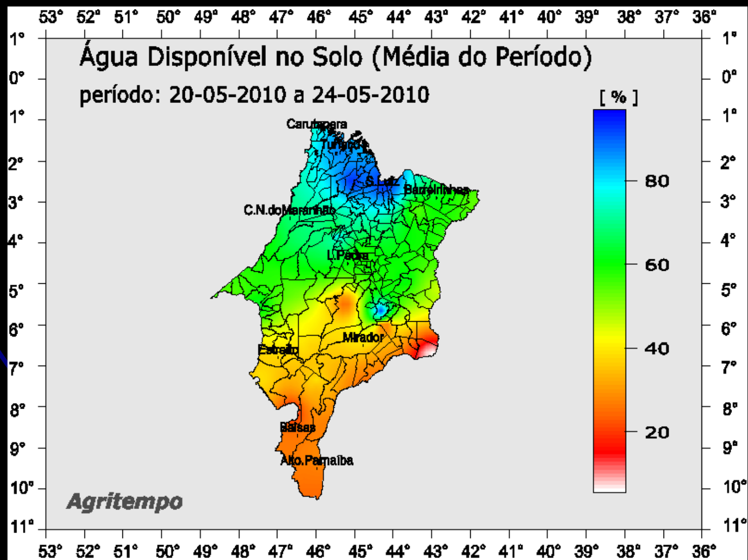
% of Soil Available Water
October 2009



Climatological Water Balance Monitoring - Brazil







Complex WB Models

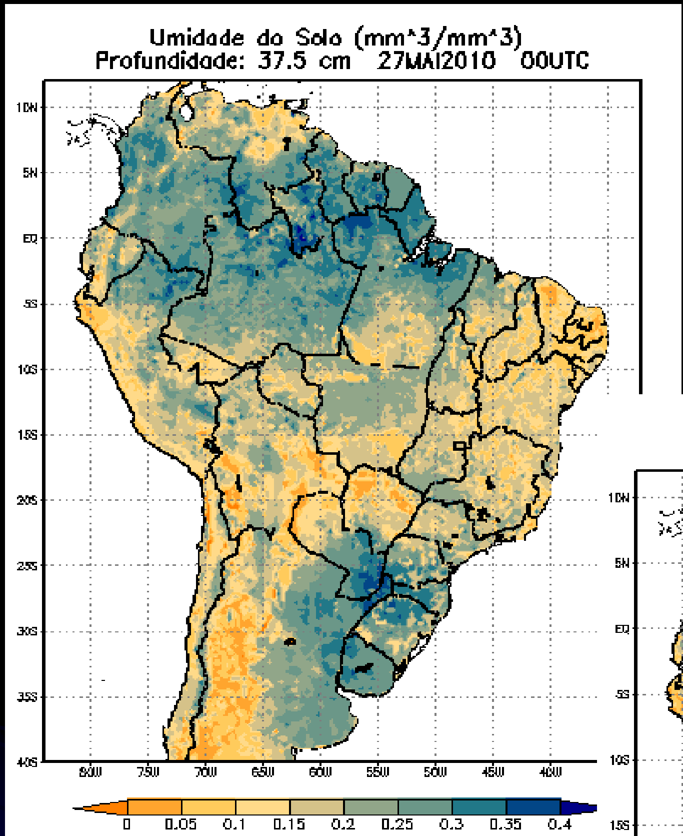
Hydrological WB (Richard's Equation)

$$\frac{\partial \eta}{\partial t} = -\frac{\partial}{\partial z}\left(D_\eta \frac{\partial \eta}{\partial z} - K_\eta \right) + S_\eta$$

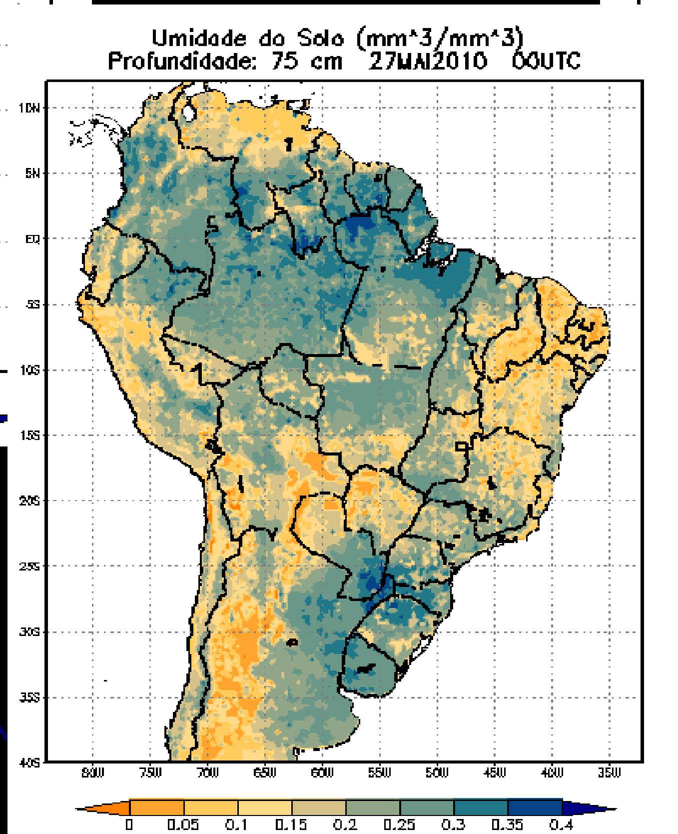
where Dn i the soil hydraulic difusivity, Kn the soil hydraulic conductivity, z the depth of the root zone, and Sn corresponds to a volumetric parameter associated to the extraction of water by the roots and water state exchanges (ET). Dn, Kn e Sn are parameterized as functions of soil type and vegetation. Real soil texture and the current land use will help to describe the biophisiological and edaphic characteristics of the respective systems.

This procedure is used by CPTEC/INPE in Brazil to assess soil water content , from P and ETP satellite data, and pedo-transfer functions to characterize soil conditions.

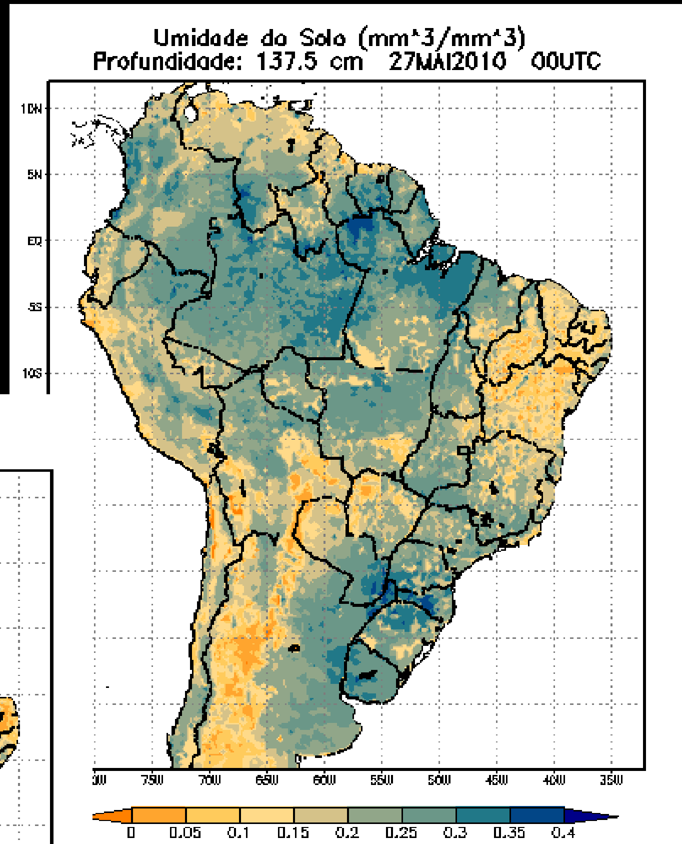
Hydrological WB (Richard's Equation)



Depth = 37,5 cm



Depth = 75 cm



Depth = 137,5 cm

MUSAG WB

(Soil Moisture Model for Agricultural Activities)

$$SWSf = SWSi + INF - q - Ev$$

$$Esc = P + I - INF$$

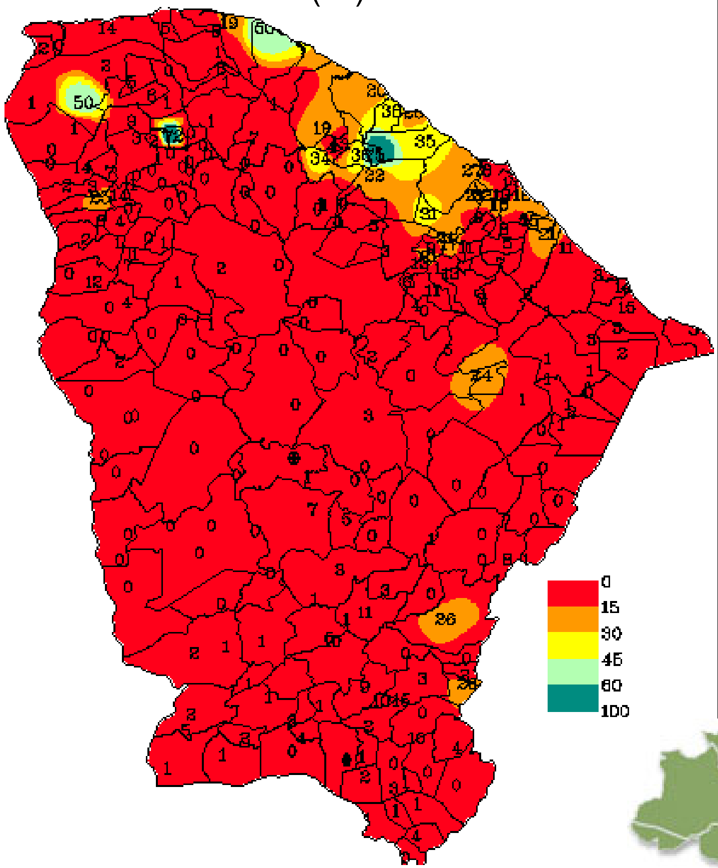
where: SWS_f and SWS_i are respectively the soil water storaged at the beginning and at the end of the period (one day).

INF is the infiltration; q é the water which was drained; Ev is the water evaporated, since the model was developed for bare soil.; Esc is the runoff; P is the rainfall accumulated in the last day, and I is the irrigation in the last day.

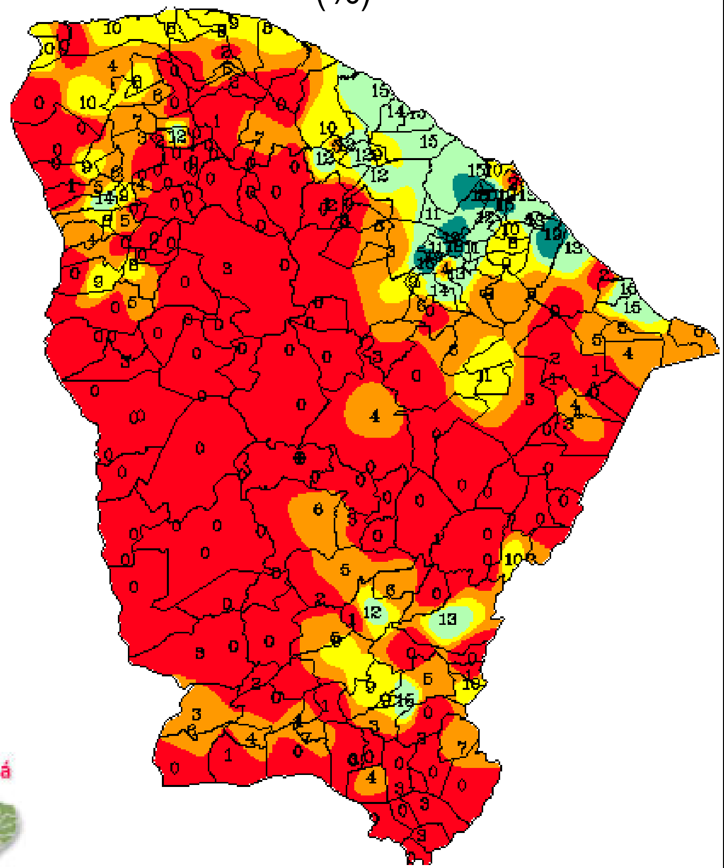
Input data: SWSi; Soil Hydraulic Characteristics (Pedo-Transfer Functions); Rainfall; and ETP.

In Brazil, this model has been applied to determine the WB balance of Ceará State.

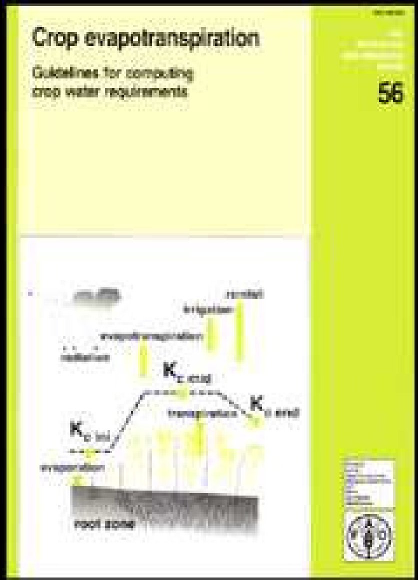
Soil Water Storage in relation to SWHC (%)

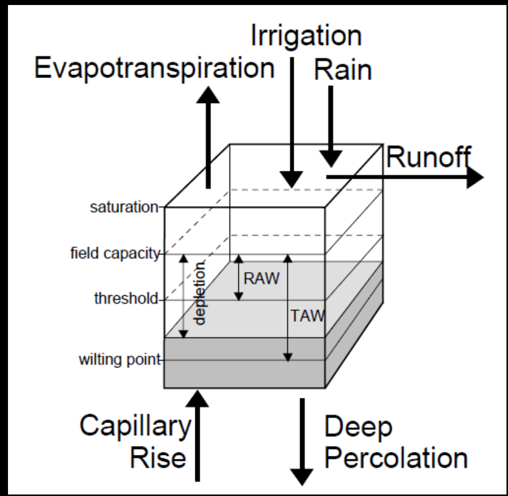


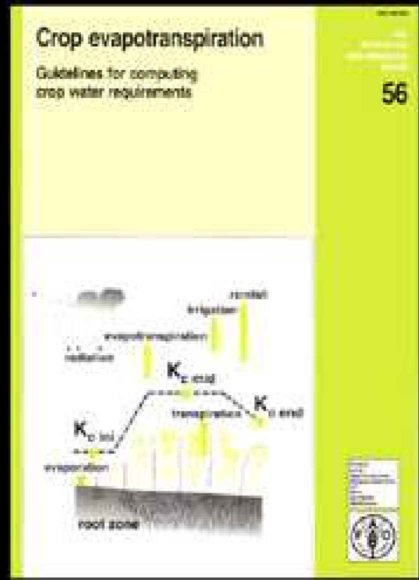
Soil Water Storage in relation to SWHC (%)

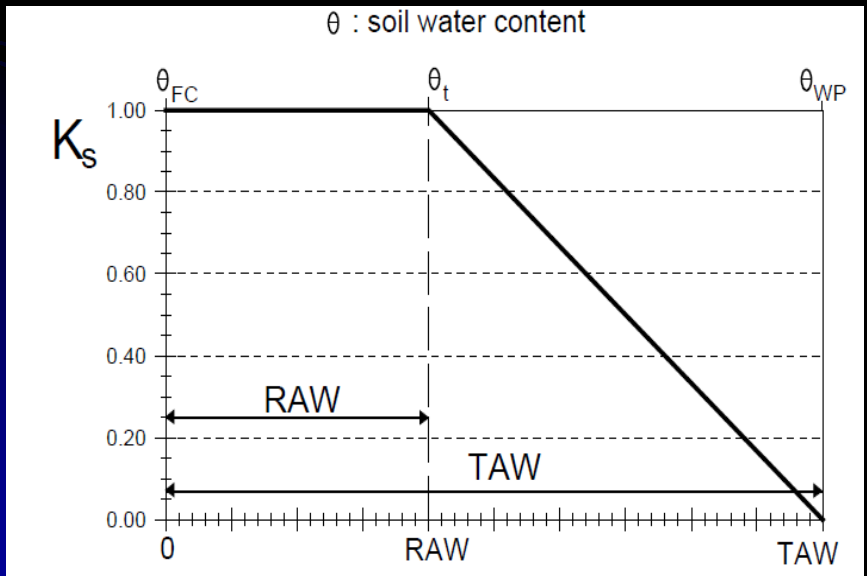


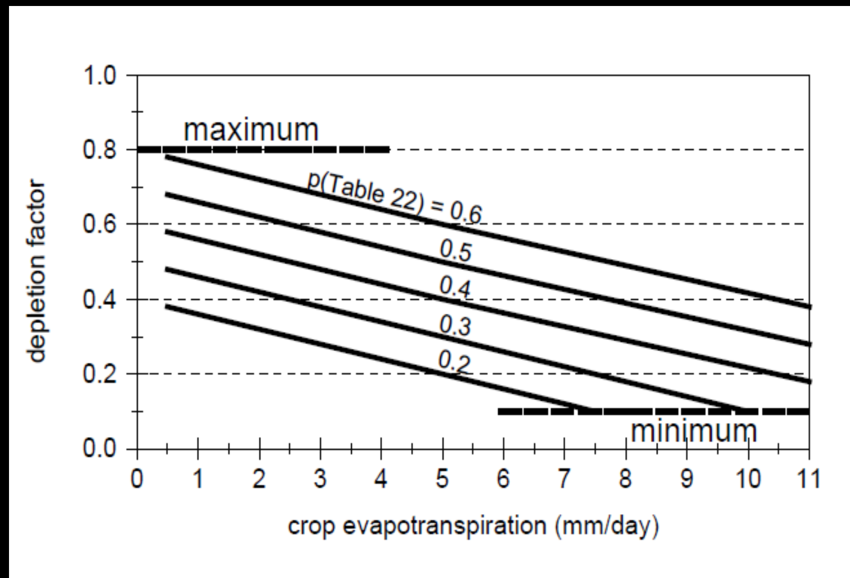
FAO56 WB Model











FAO56 WB Model

The WB of FAO56 Paper is a complex method, involving the following equations:

Total Available Water

$TAW = 1000\ (\Theta_{FC} - \Theta_{WP})\ Zr$

Readily Available Water

$RAW = p * TAW$

Water Stress Coefficient

$Ks = (TAW – Dr) / (1 –p)\ TAW$

Effective Precipitation

If $P_i < 0.2\ ETo$, then $P_i = 0$

Capillary Rise

If Water Table > 1m, then CR = 0

Adjusted ETc

$ETa = ETc\ adj = Ks * Kc * ETo$

Root Zone Depletion

$DR_i = Dr_{i-1}-(P-RO)-I-CR+ETc+DP$

Initial Root Zone Depletion

$Dr_{i-1} = 1000\ (\Theta_{FC} - \Theta_{i-1})\ Zr$

After a heavy rain $Dr_{i-1} = 0$

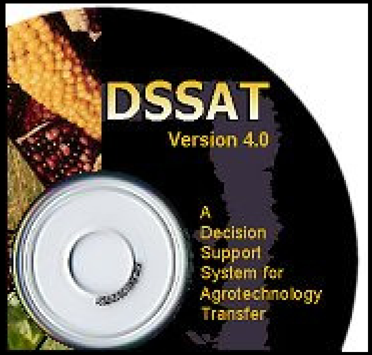
Deep Percolation

$DP_i = (P-RO)+I-ETc-Dr_{i-1}$

If $Dr_{i-1} > 0$, then $DP_i = 0$

Ritchies' Model - DSSAT

The Ritchies' WB is also a complex method, having as inputs the following variables:



Inputs

Soil characteristichs

Climate parameters

Crop management practices

Plant growth variables (estimated by DSSAT crop models)

Calculations

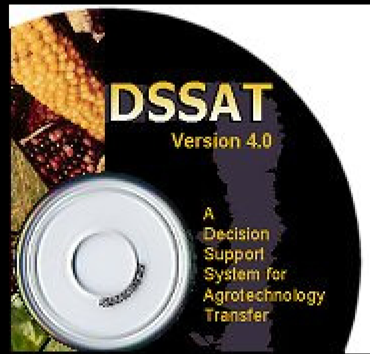
Soil water flow upwards and downwards trough profile

Drainage with a "cascading" approach, layer by layer

E (for 0 to 5 cm) + T (for the root zone) = ET

Ritchies' Model - DSSAT

Calculations



Root Water Uptake (RWU):

RWU = [1.32*Ke / (7,01 – Ln RLV)]

Soil Hydraulic Conductivity (Ke)

$Ke = 10^{-5}\, e^{[CON(SWS - LL)]}$

CON = 120 – 250 LL

L > 0,3 cm^3/cm^3, CON = 45)

RLU = root length density, simulated by DSSAT crop models

LL = lower limit of SWS

$$q_i = -\left[\frac{\left(K_{oi+1} - K_{oi}\right)}{2}\right]\left[\frac{\left(\Psi_{i+1} - \Psi_i\right)}{\Delta Z_i} + 1\right]\Delta t \qquad (4)$$

q is infiltrated depth in the top of the compartment

Performance of Ritchies' Model - DSSAT

Original Ritchies' Model

Calibrated Ritchies' Model

Observed

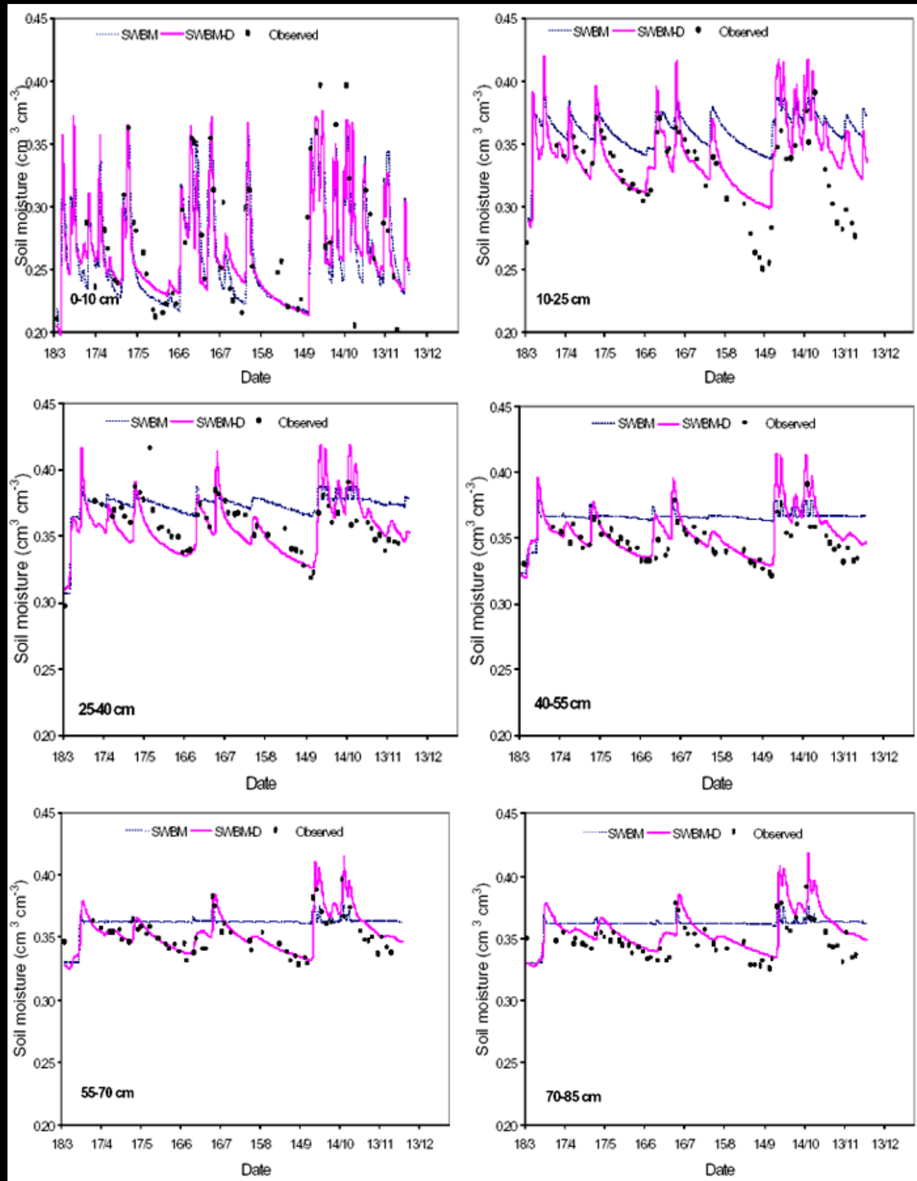
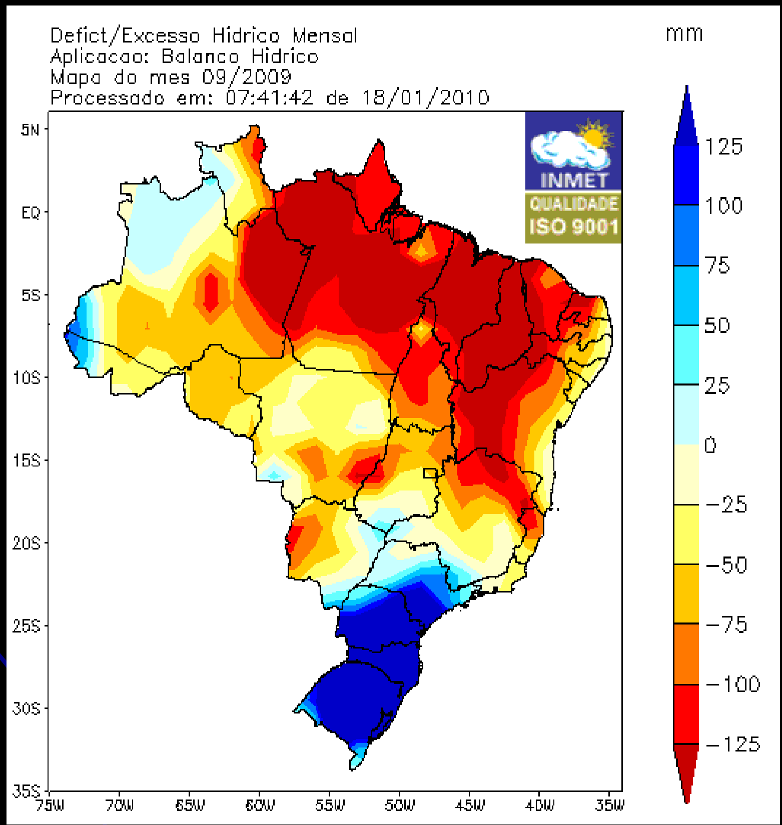


Figure 2 - Observed and simulated soil moisture by the water balance module of DSSAT (SWBM) and by the modified module for calculation of soil water flux (SWBM-D), according to different depths in a bare soil.

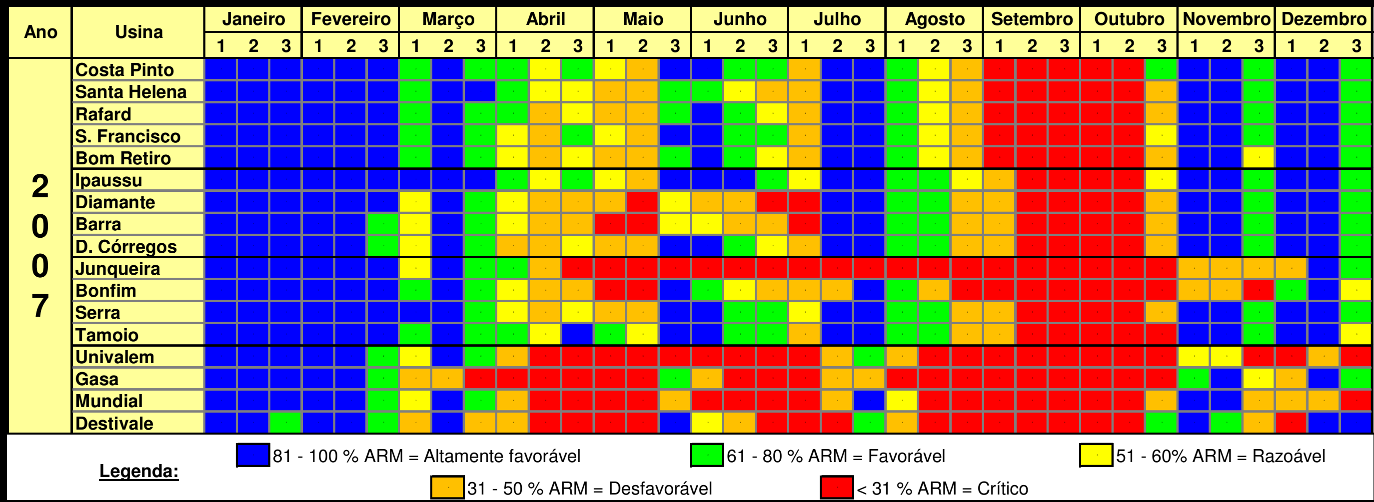
Water Balance as a Tool for Agricultural Drought Monitoring

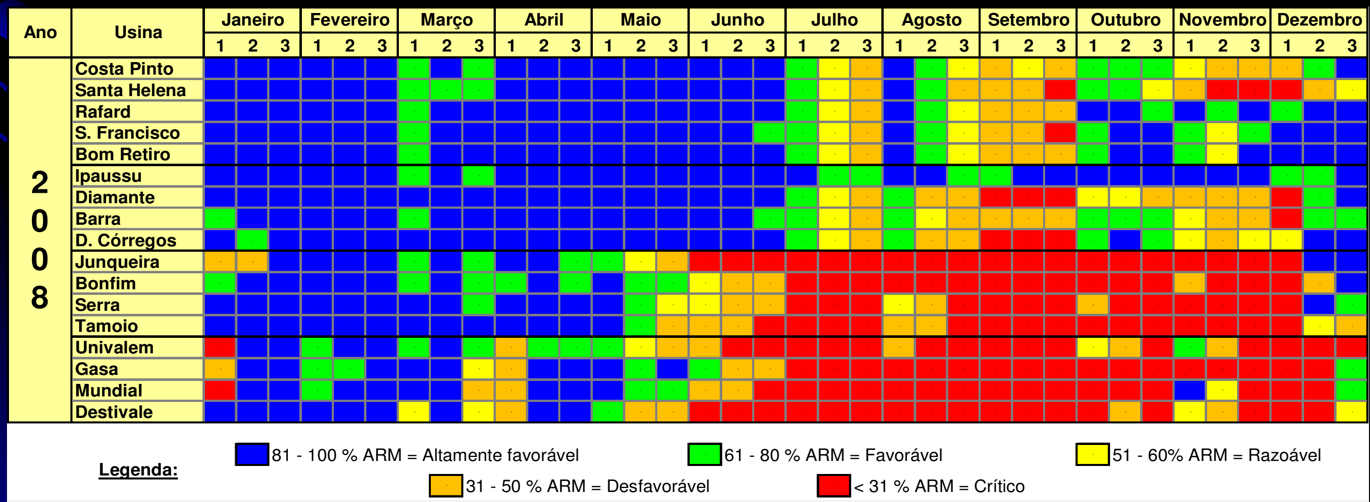
Accumulated Water Deficiency (WD)



Water Balance as a Tool for Agricultural Drought Monitoring

Soil Water Storage for Crop Development

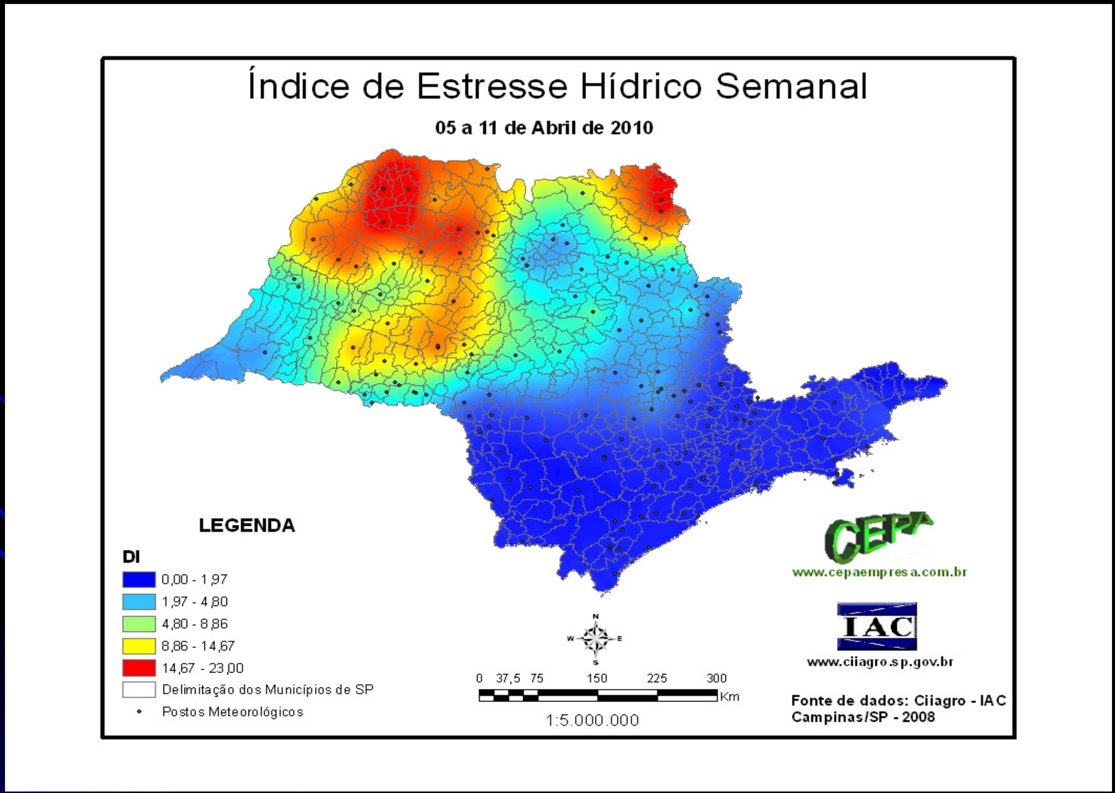




Water Balance as a Tool for Agricultural Drought Monitoring

Relative Water Deficiency Index

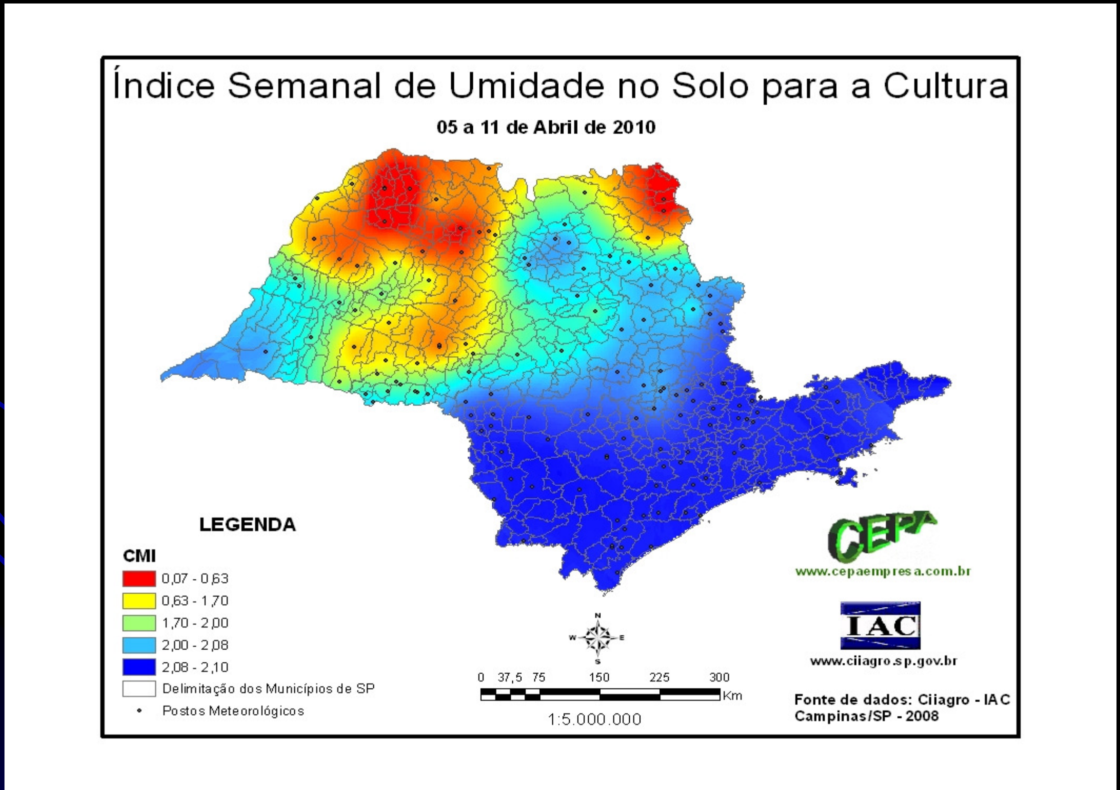
$$DI = (1 - ETa / ETP) * 100$$



Water Balance as a Tool for Agricultural Drought Monitoring

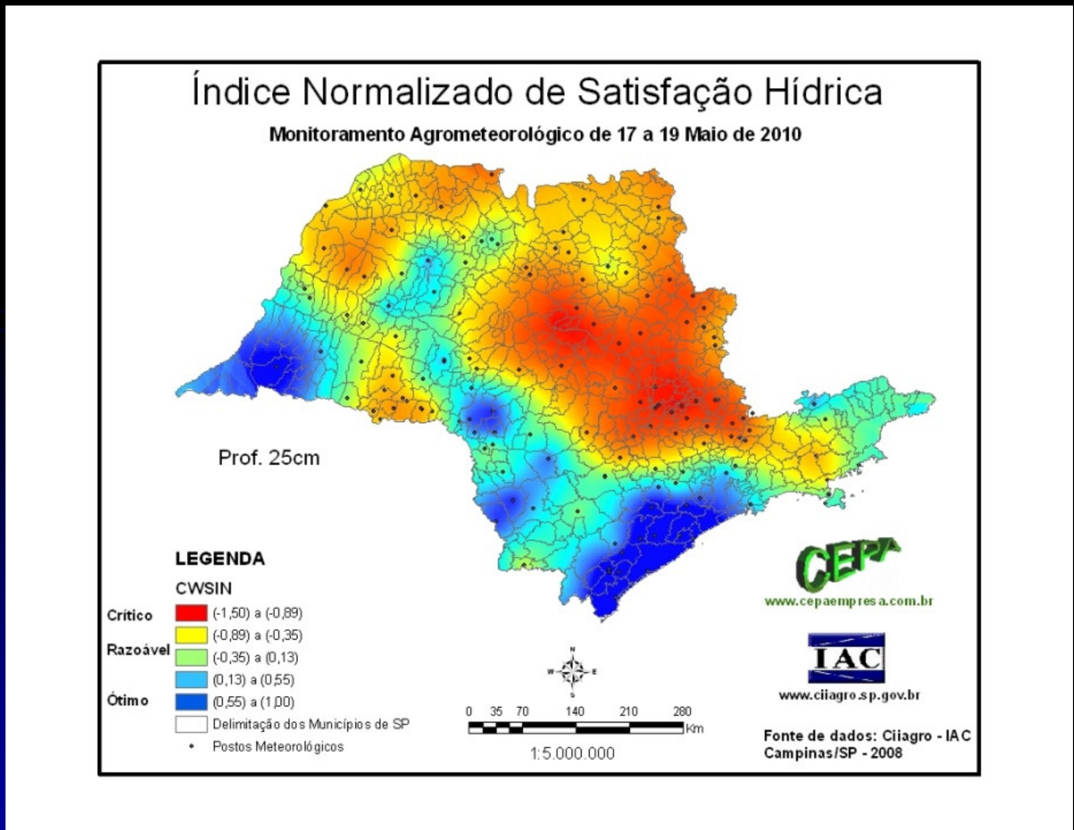
Crop Moisture Index

CMI = ETa observed – ETa expected



Water Balance as a Tool for Agricultural Drought Monitoring

Crop Water Development Index



$$CWDF = SWS / SWHC$$

$$CWDI = (CWDF/0.40) - 1$$

$$ACWDI = \sum (CWDI/n \, . \, 1.5)$$

Strengths, Weaknesses and Limitations of Water Balance Models for Drought Monitoring

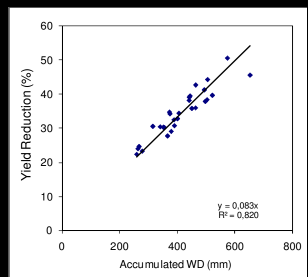
Simple Water Balance Models

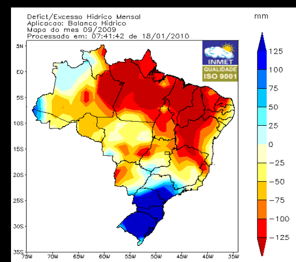
Strengths

- Simple;
- Easy to apply;
- Requires only Rain, ETP and SWHC as inputs;
- The outputs are easy to understand and apply;
- Does not require much computational power;
- Water deficiency has a high correlation with crop yield losses.

Weaknesses

- Does not consider runoff, rain interception, soil characteristics; etc.
- SWHC is determined mainly arbitrarily;
- Can be associated with systematic errors.





Strengths, Weaknesses and Limitations of Water Balance Models for Drought Monitoring

Complex Water Balance Models

Strengths

- The results are trustable when well calibrated for the location;
- They consider the majority of the processes involved with the WB;
- The results normally are very well correlated to what is happening in the field, in terms of water deficit.

$$q_i = -\left[\frac{\left(K_{oi+1} - K_{oi}\right)}{2}\right]\left[\frac{\left(\Psi_{i+1} - \Psi_i\right)}{\Delta Z_i} + 1\right]\Delta t \qquad (4)$$

Weaknesses

- They require several data, which are not readily available;
- Complex to apply;
- Require detailed information from soil, crop development, crop management, and climate;
- The outputs are more complex;
- They need higher computational power;
- Can present calibration errors.

Final Remarks

√ The WB is an important tool for determining Agricultural Drought Index, since it take into account variables from soil, crop and climate, and use to have a high correlation with yield losses;

√ However, its use requires attention, mainly in terms of the errors associated to the estimates. Complexity does not necessarily represent improvement in accuracy;

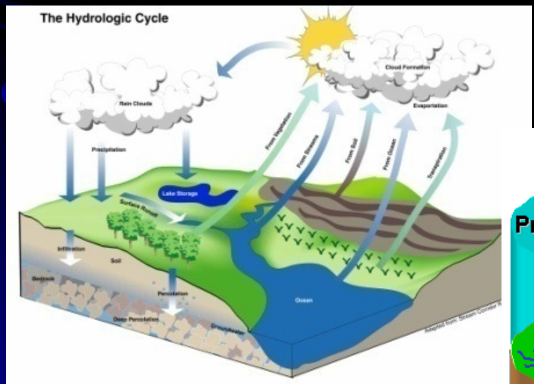
√ The simple models can be as much efficient as the complex models, since tested and adjusted for the regions of interest;

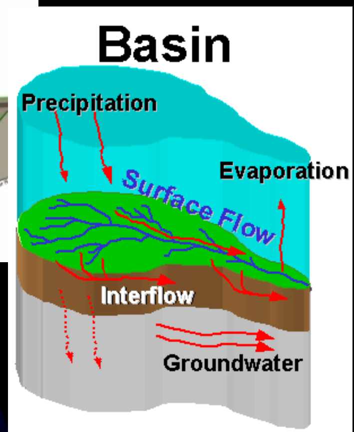
√ The complex models vary among them, but in general they can produce very accurate results, mainly after its parameterization for the crop, management and location.

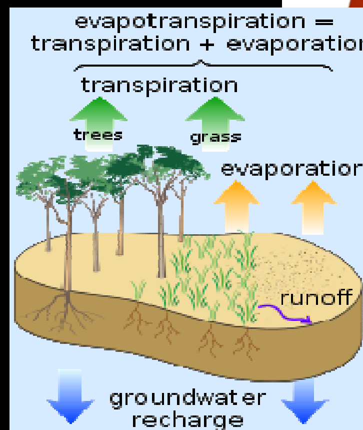
Final Remarks

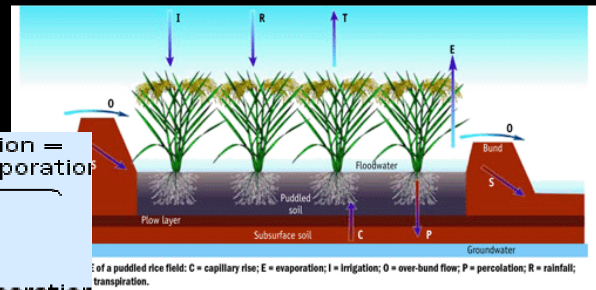
√ Data availability is crucial to decide which kind of WB to adopt. Simple WB only requires P, ETP and SWHC data; whereas Complex WB will require also crop and management data;

√ Independent of the kind of the WB used, simple or complex, calibration and test are essential to the success of them as agricultural drought indicator.









Thanks Gracias Merci Obrigado

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