Linking seasonal and long-term climate information to agricultural productivity

A case study for Central Africa

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Motivation:

Karlsruher Institut für Technologie

- **Rainfall** = major limiting factor for agriculture in sub-Saharan Africa

- **Economies of SSA** highly exposed to rainfall variability
  - ➢ Agriculture accounts for 35% of the GDP, employs 70% of population
  - ➢ > 95% of cropland managed under **rainfed conditions**
  - ➢ High rainfall variability on intra-annual, inter-annual and decadal scales

- Crucial problem for **<u>rainfed</u>** agriculture: Decision about the **optimal planting date** for current season
  - ➢ Planting as early as possible to avoid wasting of valuable growth time
  - ➢ Planting too early may lead to crop failures and high economic losses

- CC will aggravate rainfall variability and water scarcity in 21. Century

“Challenge” for agricultural management under rainfed conditions in sub-Saharan Africa

Scientifically sound information for decision support under present and future climate conditions and weak infrastructure

„Challenges“ … more specifically

- **Development of agriculturally relevant ORS approach**
  - **optimal planting rules accounting for intra-seasonal variability of rainfall**

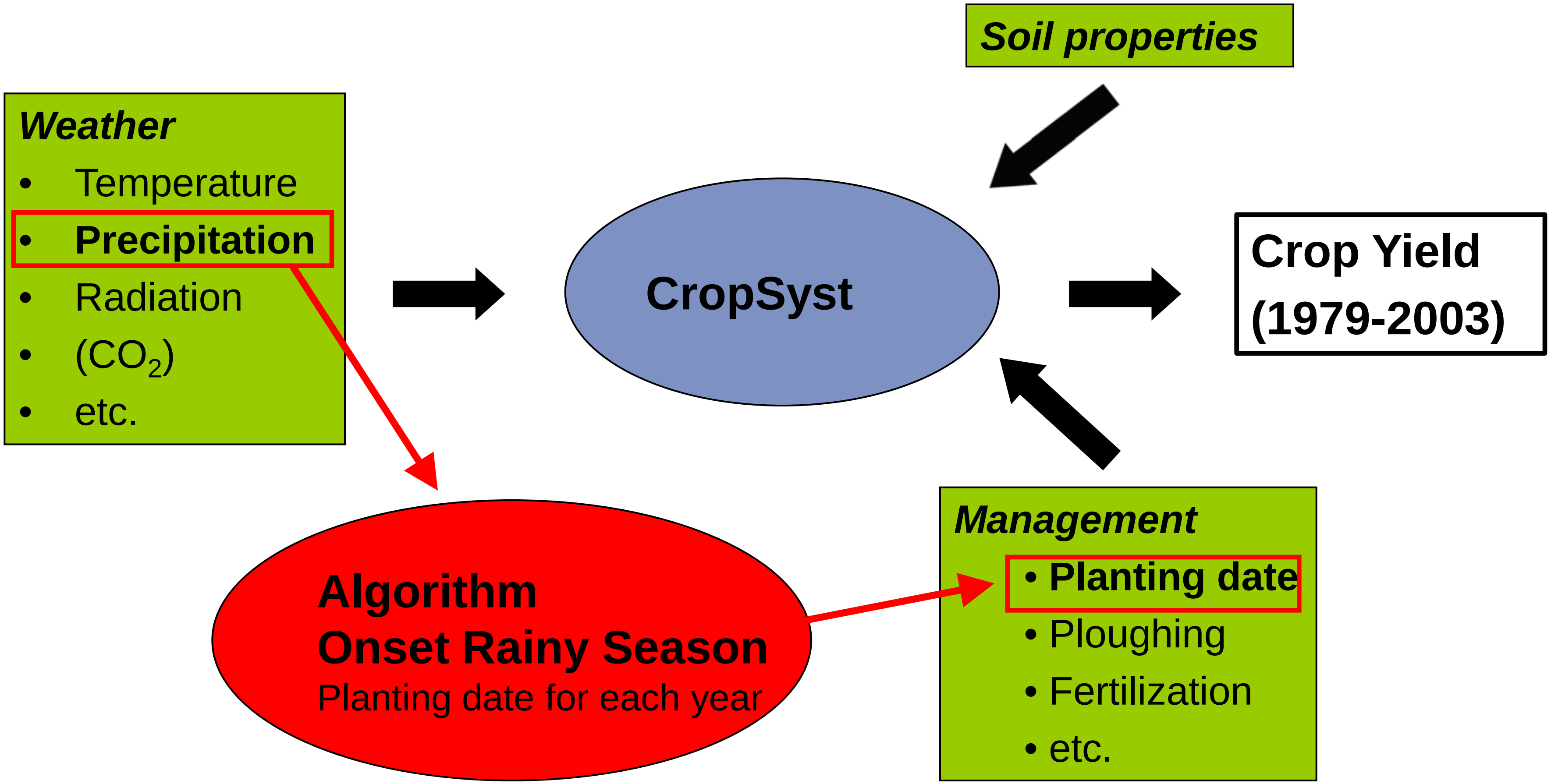
- **Estimate the impact of planting date on “attainable” crop yield under current and future climate conditions**

Potential Solutions

- **Development “*optimal planting date following crop modeling system*”**

- **Application for past and future and comparison to traditional planting dates**

"Optimal planting date following crop modeling system"



CropSyst model (Stöckle et al., 2003)

- **Multi-year, multi-crop process-based simulation model** to study the effect of climate, soil, and management on productivity and environment of cropping systems

- **Calibration:** Parameterization of crop-specific values (e.g. phenology) by IRA (Cameroon) and literature review

- **Validation**
  - Difference modeled and observed yields acceptable (< 10%)
  - Represents inter-annual and spatial variability of observed crop yield

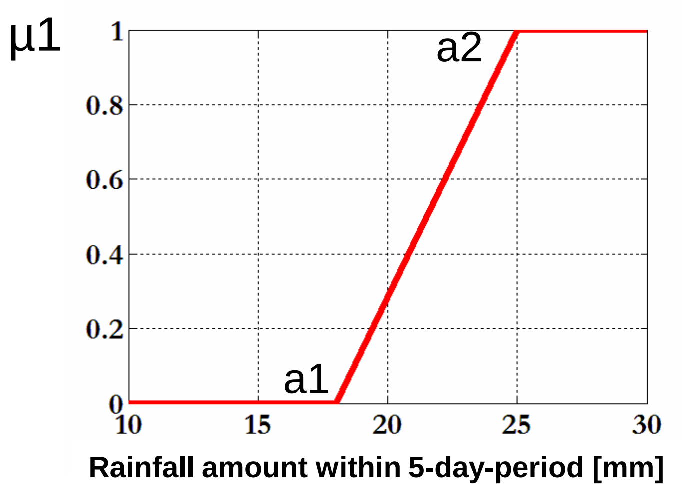
Algorithm: Onset of the Rainy Season (ORS)

- **Literature review: … many rainfall-based (threshold) approaches**
  - e.g. Stern et al., 1981: ORS as first DOY with rainfall > 20mm within 2 consecutive days)
  - Sivakumar, Hess, and many more

- **Problem:**
  - existing approaches too strict (binary logic)

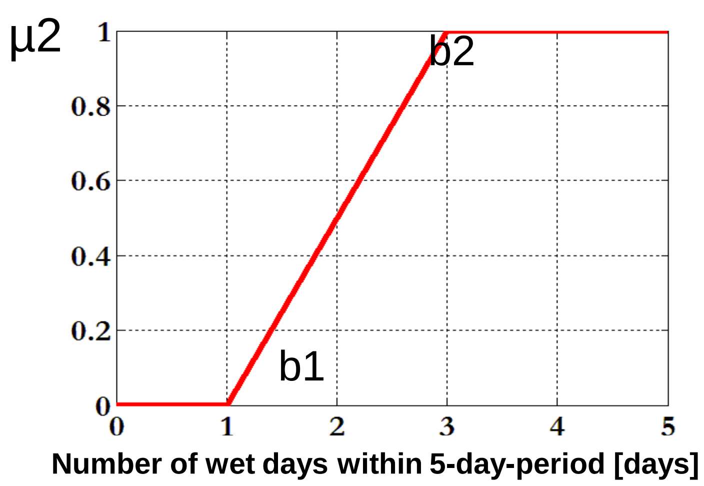
- **Solution:**
  - Fuzzy logic-based ORS approach of **Laux et al.** (2008, 2009) for Volta Basin of West Africa
  - 3 membership functions (criterions)

#1: *Rainfall amount* criterion



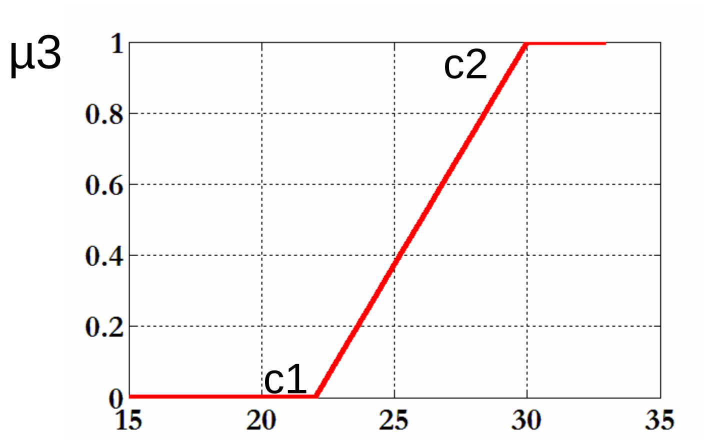
- μ1: 2 parameters a1, a2
- Sufficient water at planting stage

#2: *Multiple rainy days* criterion



- μ2: 2 parameters b1, b2
- exclude single heavy showers as ORS

#3: *False start* criterion



**Number of consecutive days after ORS,
in which no dry spell > 6 days occurs [days]**

- μ3: 2 parameters c1, c2
- exclude total crop failure

Combining #1, #2, and #3 for planting decision

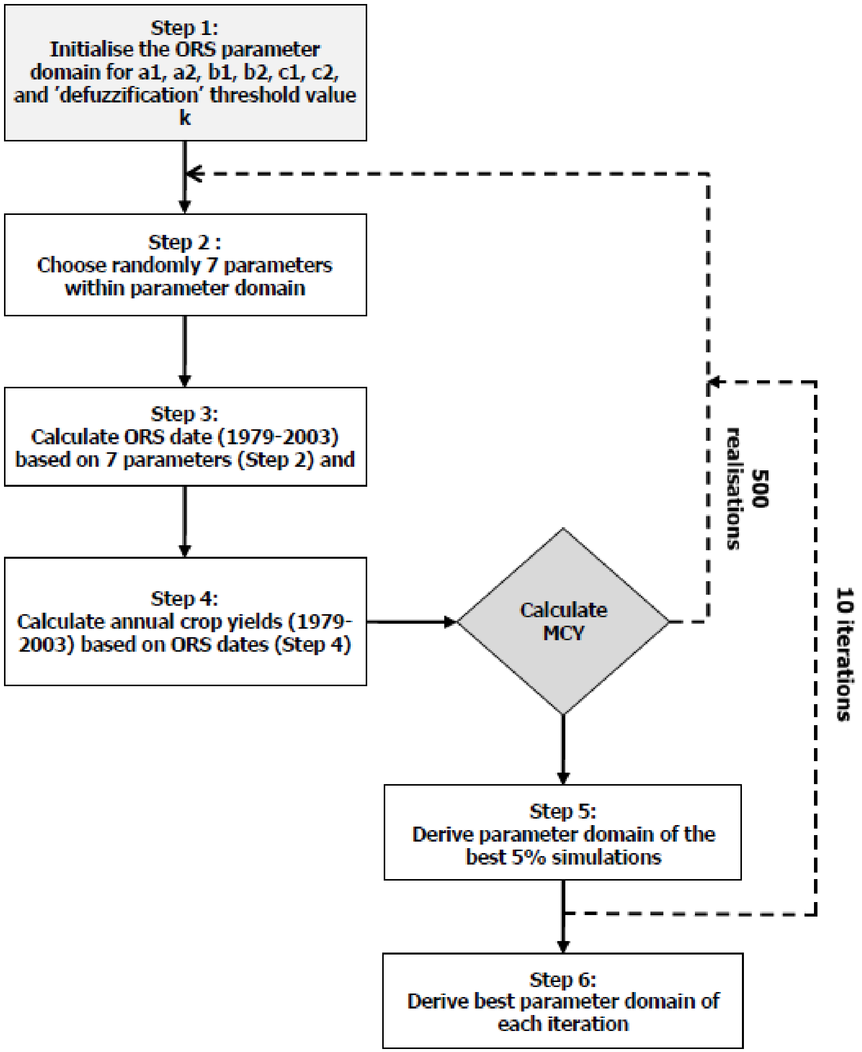
- Total membership grade:

  $\mu_{TOT} = \mu 1 \cdot \mu 2 \cdot \mu 3$

  IF μ_{TOT} > threshold k [0,...,1], THEN Onset Rainy Season (planting)

- ORS approach with **7 parameters**: k, a1, a2, b1, b2, c1, c2
- Parameters depend on **region** (weather, soil) and **plant physiological aspects**
- Optimization for each crop and station of interest

Parameter optimisation algorithm



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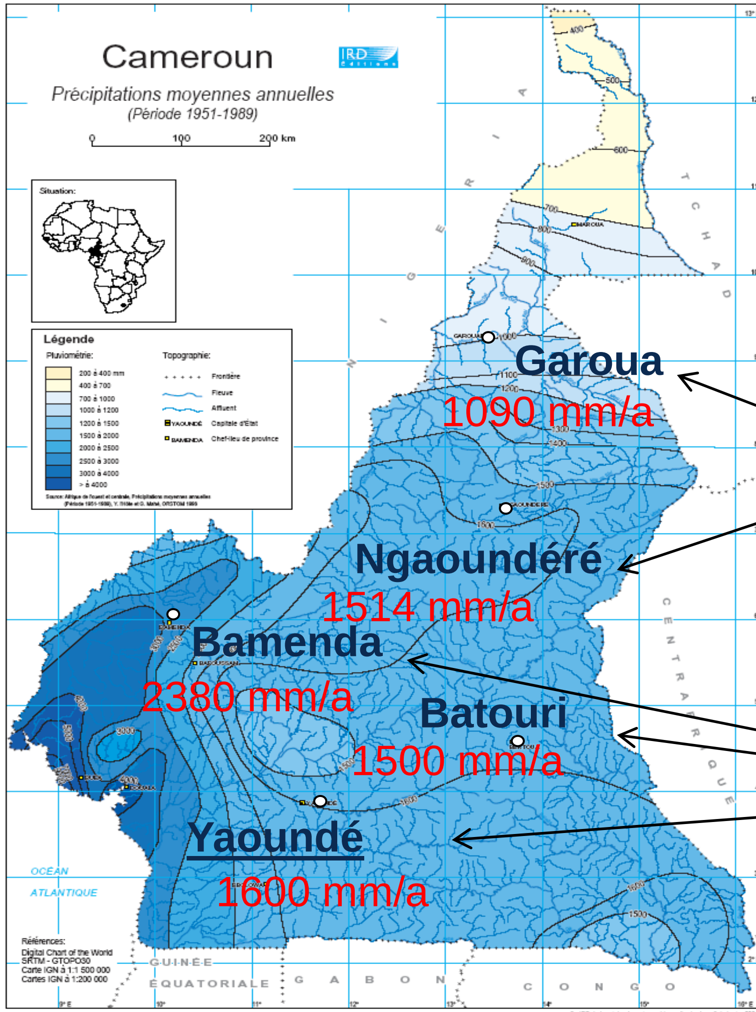
Case study: Cameroon

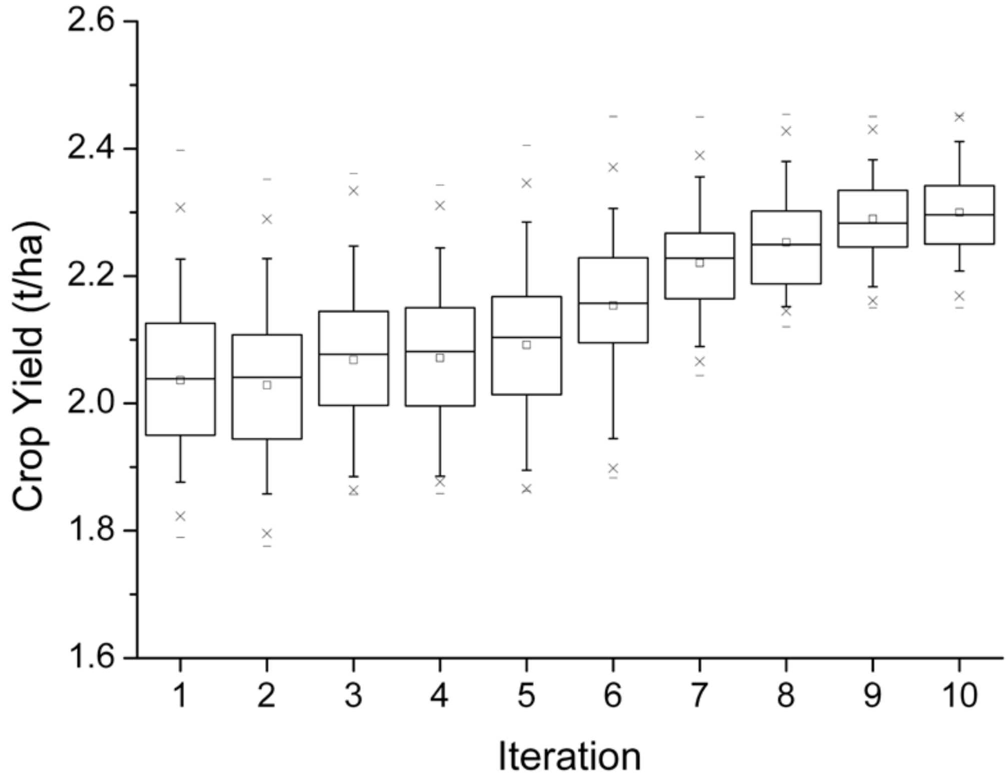


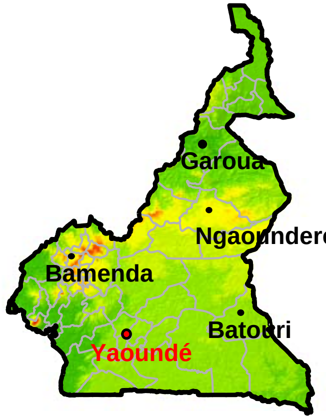
Traditional planting dates:

May 15

March 15

Results optimisation: Yaoundé (maize)





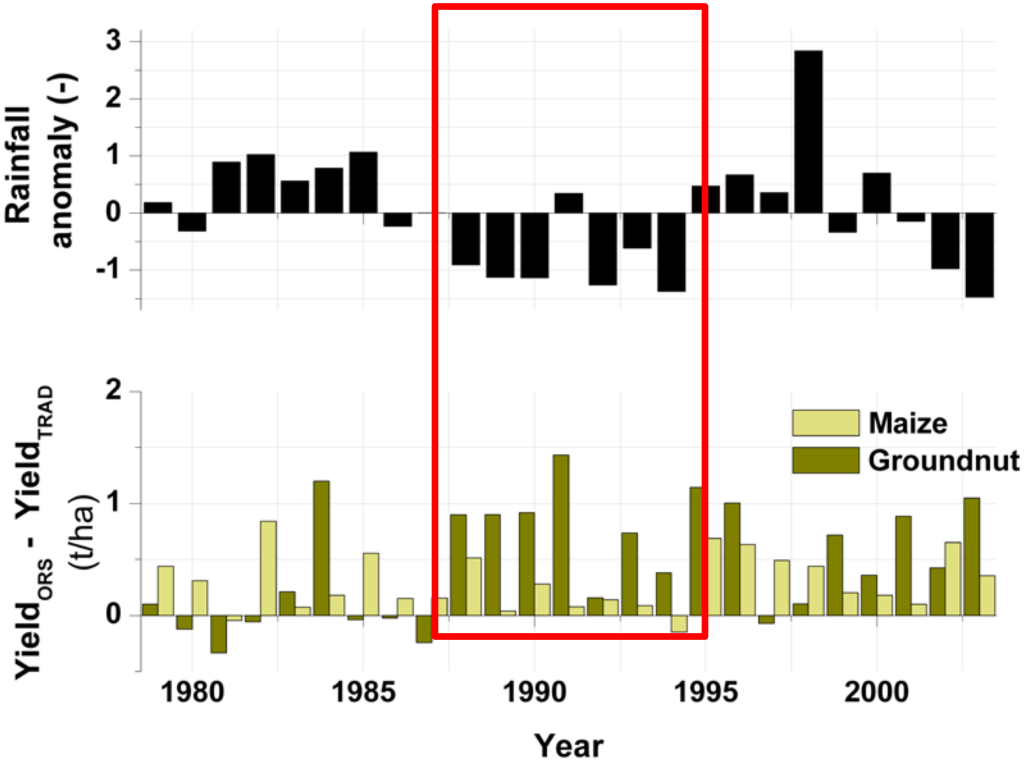
→ Mean attainable crop yield (1979-2003) increases per iteration

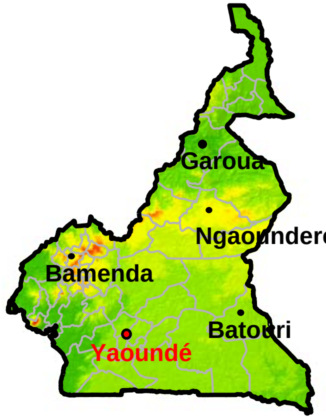
→ Distribution narrows (CV decreases)

Parameter space after 10 iterations

	μ_1		μ_2		μ_3		k		
Maize	a_1	a_2	b_1	b_2	c_1	c_2	k_1	k_2	MCY (kg/ha)
Garoua	19	29	1	5	13	26	0.46	0.81	2521
Ngaoundéré	22	30	2	5	13	34	0.45	0.76	2502
Bamenda	12	29	1	4	5	22	0.03	0.49	1261
Batouri	12	25	3	5	7	25	0.42	0.69	1561
Yaoundé	10	26	1	2	6	18	0.13	0.41	2437
Groundnut									
Garoua	15	28	1	5	11	29	0.37	0.70	1112
Ngaoundéré	12	27	1	5	7	35	0.35	0.74	1152
Bamenda	10	27	1	3	5	16	0.19	0.59	873
Batouri	11	27	3	5	7	23	0.37	0.75	1041
Yaoundé	14	24	3	5	6	24	0.36	0.74	1485

ORS algorithm vs. traditional planting calendar





Proposed new method for planting dates would have allowed for:

→ Increase in mean attainable crop yield: Yaoundé **15%**, Garoua **50%**

→ Crop yield increases in anomalous dry years

Impact of climate change on crop productivity

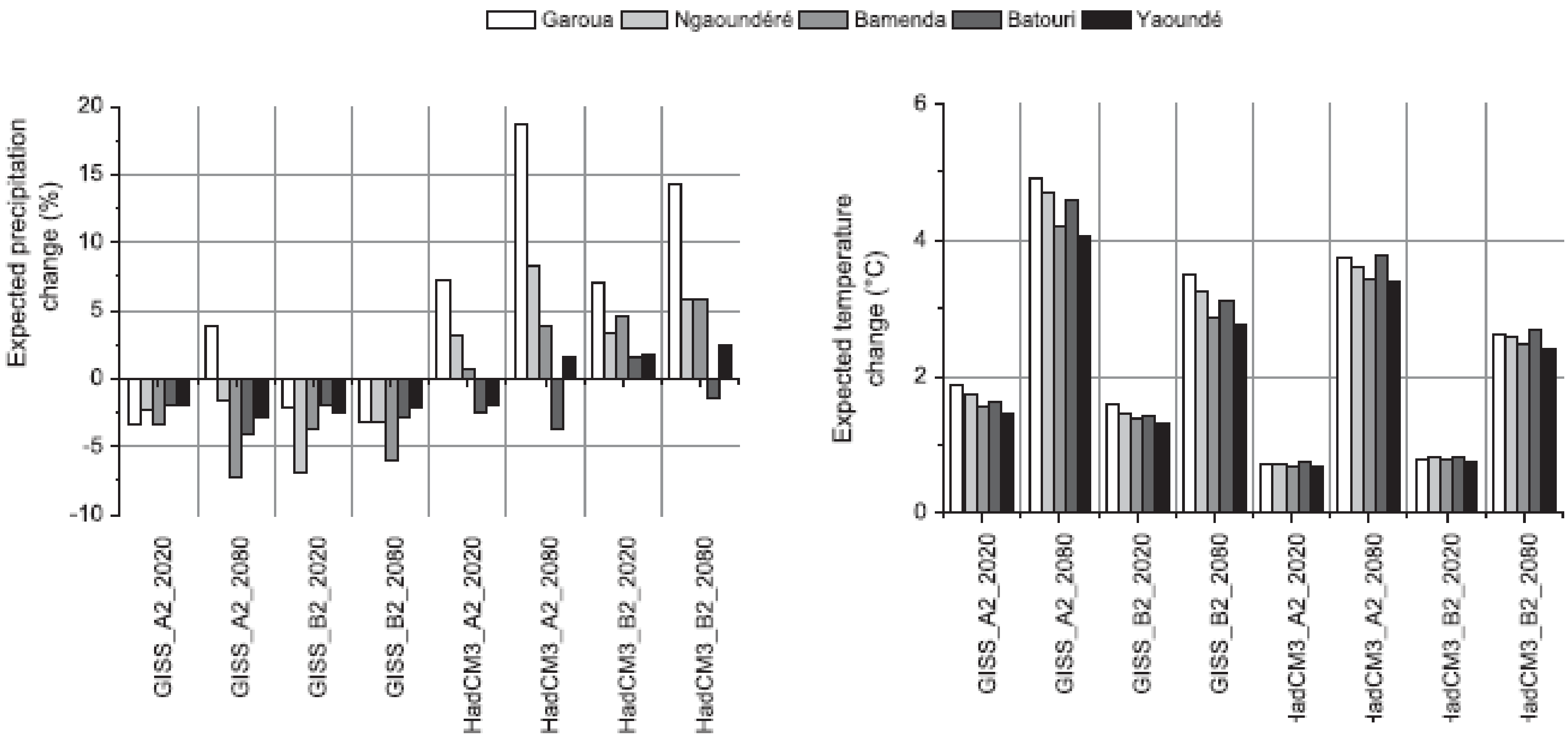
1. Daily climate scenarios for 2020s and 2080s using ClimGen based on HadCM3 and GISS, and A2 and B2 scenario (8 scenarios for each station)
   - Tmin, Tmax (Solar radiation)
   - Precipitation

2. Atmospheric CO_2 conditions for baseline period 1961-1990, 2020s, and 2080s

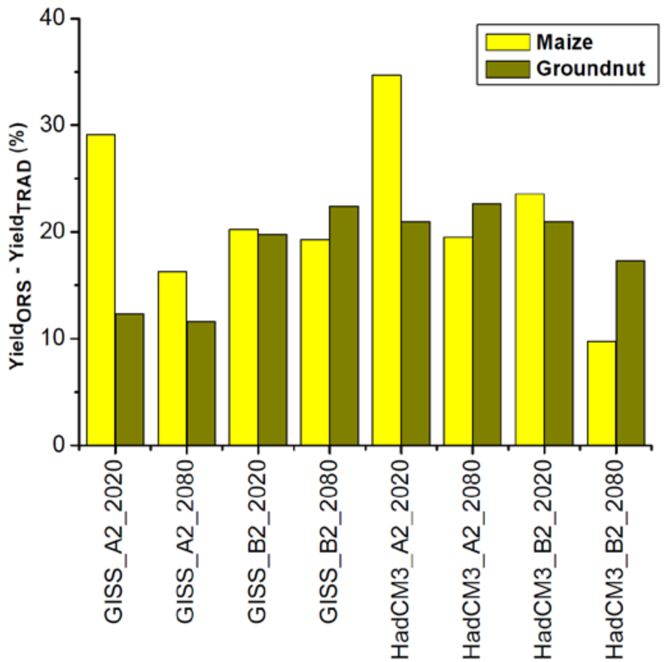
3. Crop yield simulations using future climate scenarios under baseline/future atmospheric CO_2 conditions

4. Crop yield simulations with/without adaptations of the planting date

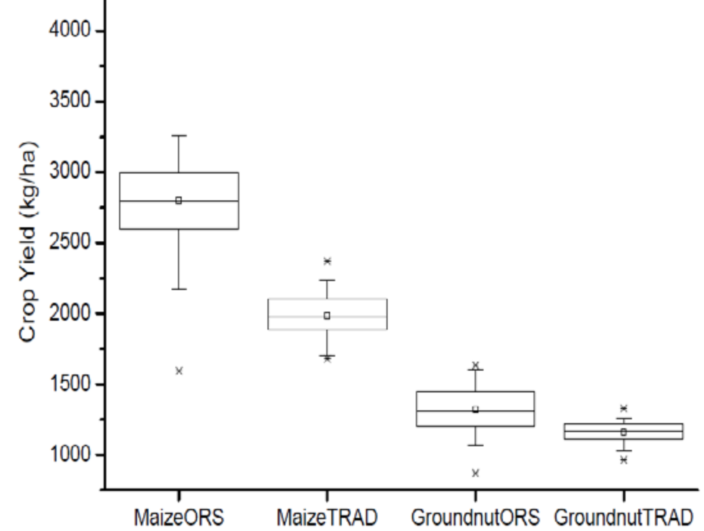
Local climate scenarios



Impact of planting date adaptations at Garoua



Distribution of mean crop yield at Garoua (2020s)



Compared to traditional planting dates:

→ Increase of groundnut (maize) yields

→ But: widened distribution for future crop yields: increase in variability!

Summary

- *Optimal planting date following crop modelling system*
  - **Optimal planting rules (crop + location)**
  - Significant **increase of mean attainable crop yield**, particularly at drier northernmost stations (Garoua, Batouri)
  - Not working for “wet conditions” (Bamenda)

- *Impact CC on future crop yield estimations*
  - Groundnut yields are expected to increase in the 2020s and 2080s, Maize yields are expected to increase (decrease) in the 2020s (2080s)
  - Using ORS approach reduces negative impacts of CC on maize yield (2080s) at northernmost stations

References

Laux, P., Jäckel, G., Munang, R. - T., Kunstmann, H. (2010): Impacts of climate change on agricultural productivity under rainfed conditions in Cameroon - A method to improve attainable crop yields by planting date adaptations, *Agricultural and Forest Meteorology* 150, pp. 1258-1271, DOI: 10.1016/j.agrformet.2010.05.008.

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Relevance for RICE-EA

- Optimized planting rules for **rainfed** rice under current and future climate conditions by coupling with dynamical and statistical crop models (e.g. ORYZA or GLAM)

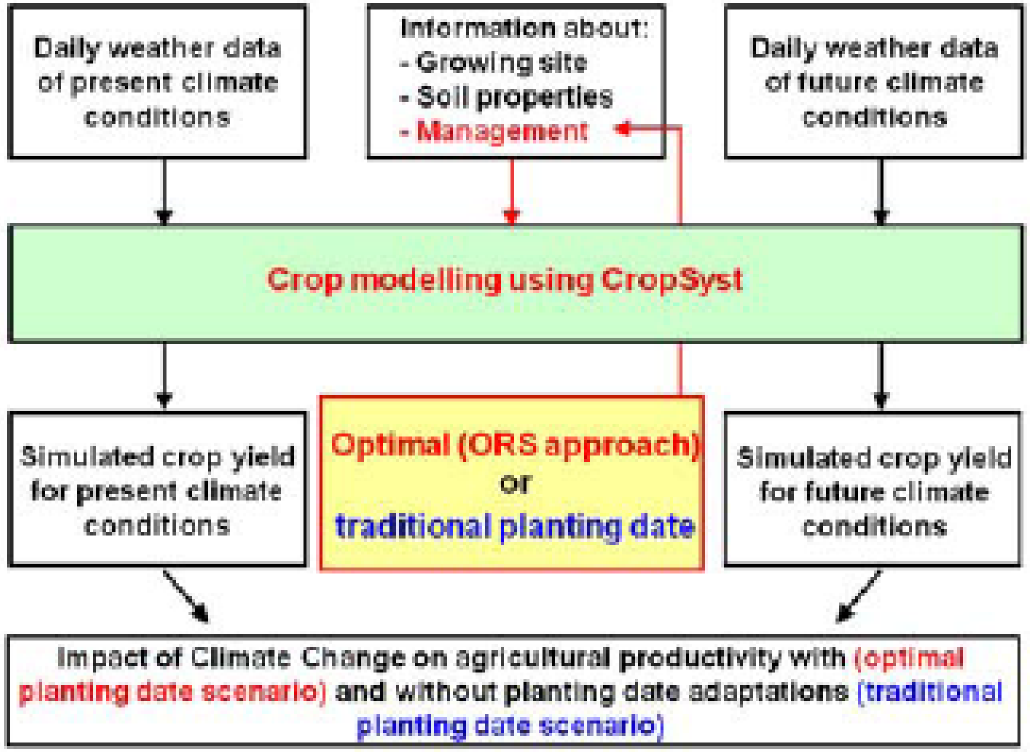
- Improvement of approach:
  - Latin Hypercube instead of Monte Carlo
  - Downscaling: RCM simulations & bias correction methods (e.g. Copulas)
  - Implementation of other constraints such as temperature thresholds for regions in higher altitudes (Kenyan highlands)

- Might also be used in combination with seasonal predictions with more direct importance for farmers


Thank you
for your attention

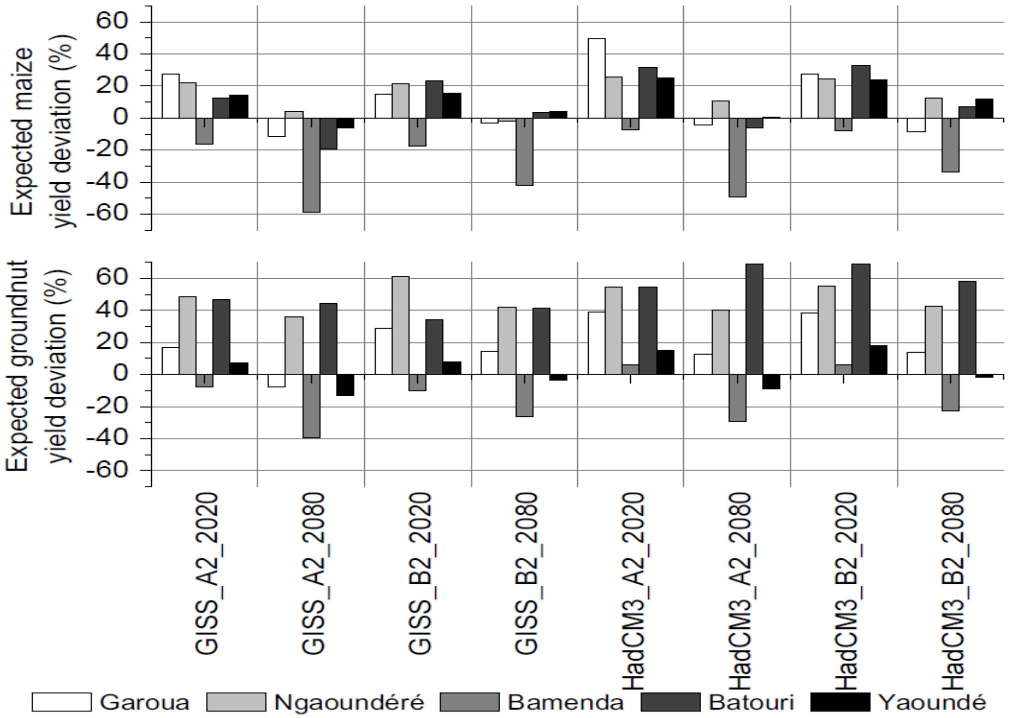
Maize	PD_{TRAD} (doy)	PD_{INIT} (doy)	PD_{ORS} (doy)
Garoua	135	211	215
Ngaoundéré	135	162	168
Bamenda	75	108	72
Batouri	75	169	171
Yaoundé	75	65	51
Groundnut			
Garoua	135	211	214
Ngaoundéré	135	144	137
Bamenda	75	91	75
Batouri	75	164	176
Yaoundé	75	158	177

Impact planting dates on future crop yield



- **GISS** and **HadCM3** A-OGCM, **A2** und **B2** scenario
- **ClimGen** for statistical downscaling of GCM output

Direct CO_2 effects + ΔP & ΔT + planting date adaptations



Compared to baseline 1961-1990:

→ Increase of groundnut yields for the 2020s and 2080s

→ Increase (decrease) of maize yields for the 2020s (2080s)

→ Aggravation of growing conditions for Bamenda

Calibration/Validation CropSyst

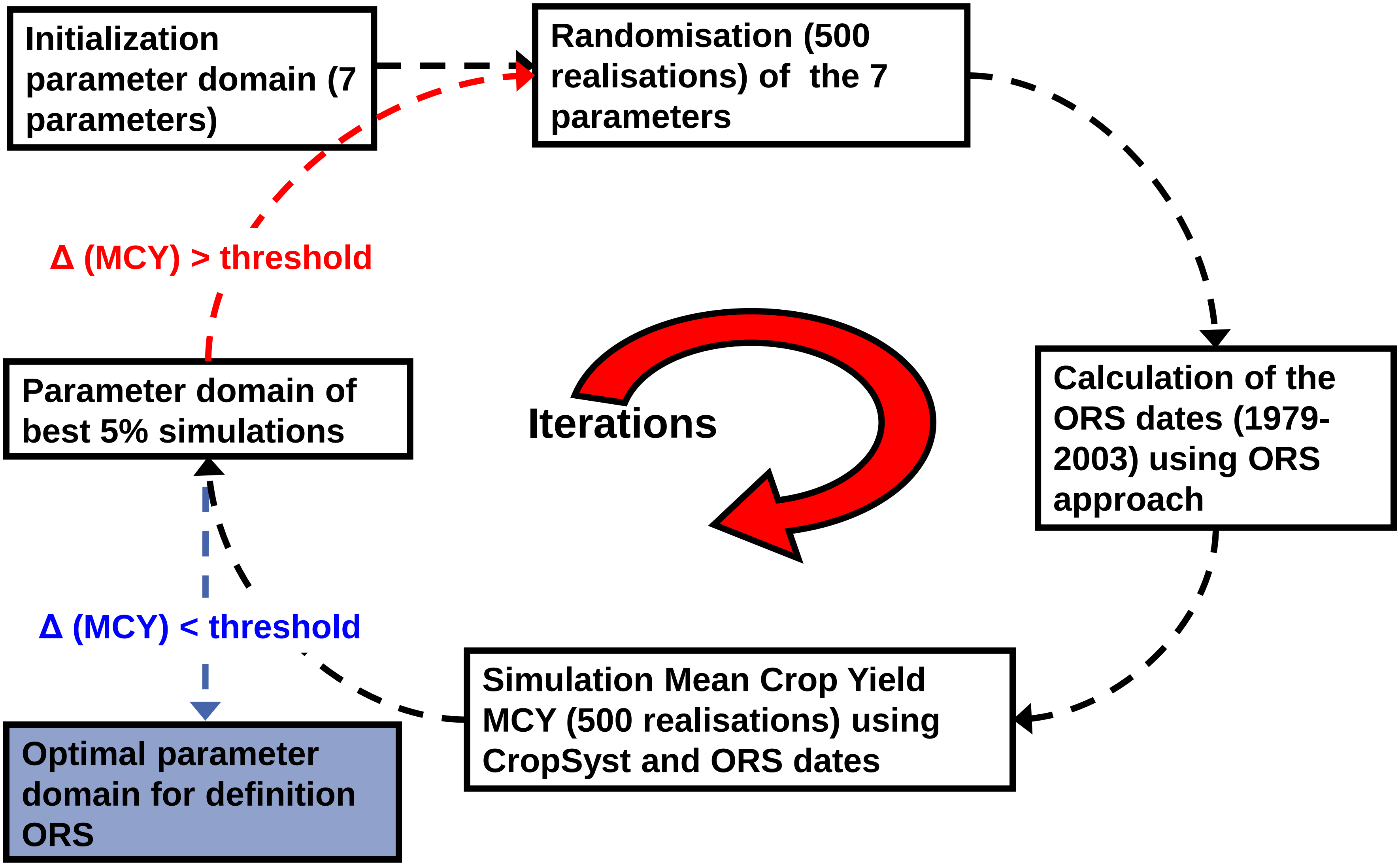
- Parametrisation crop-specific values (maize, groundnut)
  - Publications (e.g. Tingem et al., 2008)
  - CropSyst user manual

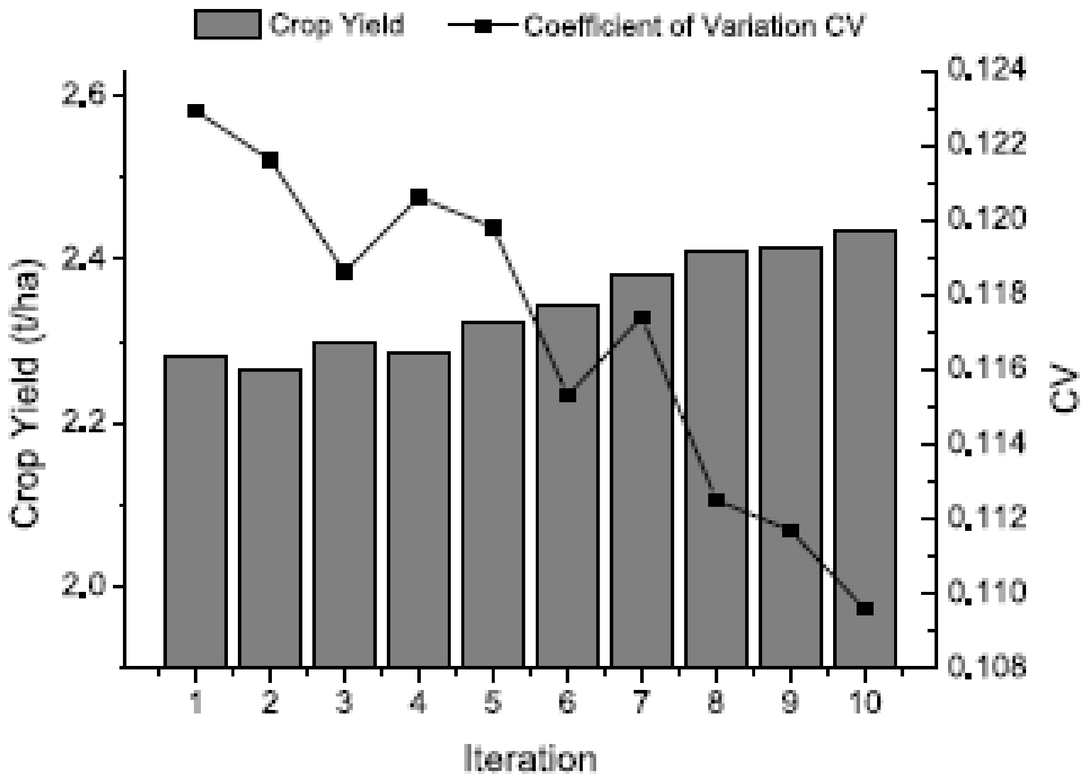
- Phenological parametrisation (e.g. GDD)
  - Institute of Agricultural Research (IRA) Cameroon

- Validation: 5-year-period of observed yields:
  - Difference between modeled and observed yields acceptable
  - Interannual and spatial variability of crop yields

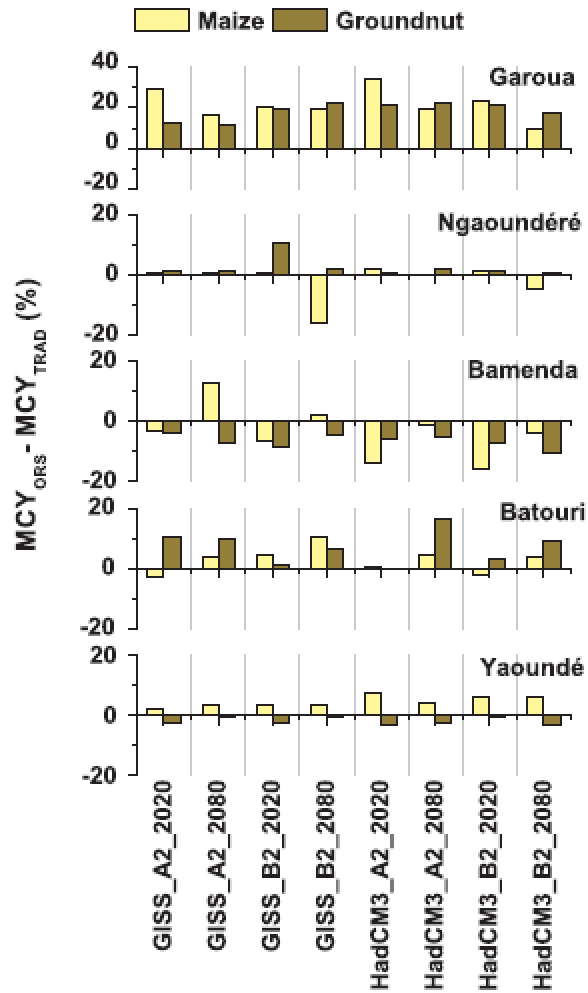
Bild Validation

ORS parameter optimisation





Crop Yield
Coefficient of Variation CV
Crop Yield (t/ha)
2.6
2.4
2.2
2.0
0.124
0.122
0.120
0.118
0.116
0.114
0.112
0.110
0.108
CV
1
2
3
4
5
6
7
8
9
10
Iteration



Maize
Groundnut
40
20
0
-20
Garoua
Ngaoundéré
Bamenda
Batouri
Yaoundé
MCY_ORS - MCY_TRAD (%)
GISS_A2_2020
GISS_A2_2080
GISS_B2_2020
GISS_B2_2080
HadCM3_A2_2020
HadCM3_A2_2080
HadCM3_B2_2020
HadCM3_B2_2080

Cameroon: Factors affecting rainfall variability

High spatial and temporal rainfall variability

- Climate: semi-humid (South) to semi-arid (North)
- *Intertropical Convergence Zone* (ITCZ)
  South: bimodal (april/may & september/october)
  North: unimodal (august/september)
- Topography