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Integrating physiology, Crop Modeling and Genetics to Tackle Thermal Stresses in Rice:

The RIDEV Approach

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Jean-Christophe Soulie (CIRAD)

funded by GEZ, AfricaRice, CCAFS and CIRAD

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Topics

- Thermal factors affecting rice production
- History: Sahel irrigated rice and the 1st RIDEV tool
- New aspects: Transpiration cooling and TOA
- A multi-environment study on rice microclimate
- Modeling micro-climate based phenology and sterility with RIDEV V.2
- Applications of RIDEV V.2
  - Mapping of thermal risks
  - Heuristic phenotyping of phenology and thermal sterility
- Outlook

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Rationale

- Thermal adaptation is fundamental for agro-ecological fit and fitness
- CC is changing thermal environments
- Rice as species has diverse thermal adaptation, but broadly adapted genotypes are rare
- Accuracy of crop models is still poor re. thermal effects
- We need…
  - Better predictive tools to map CC impact
  - Better understanding of adaptive traits

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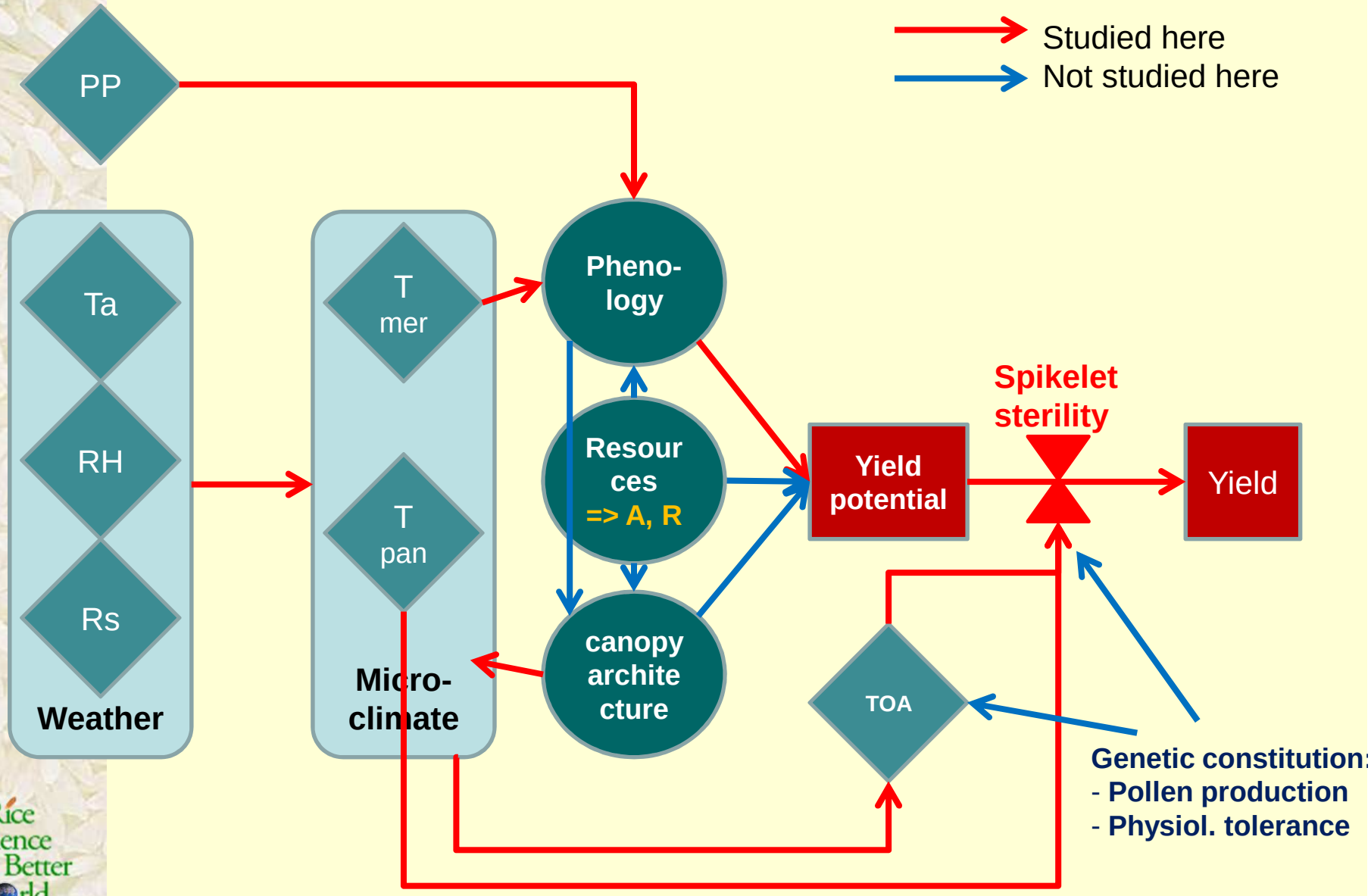
Some thermal factors affecting rice production



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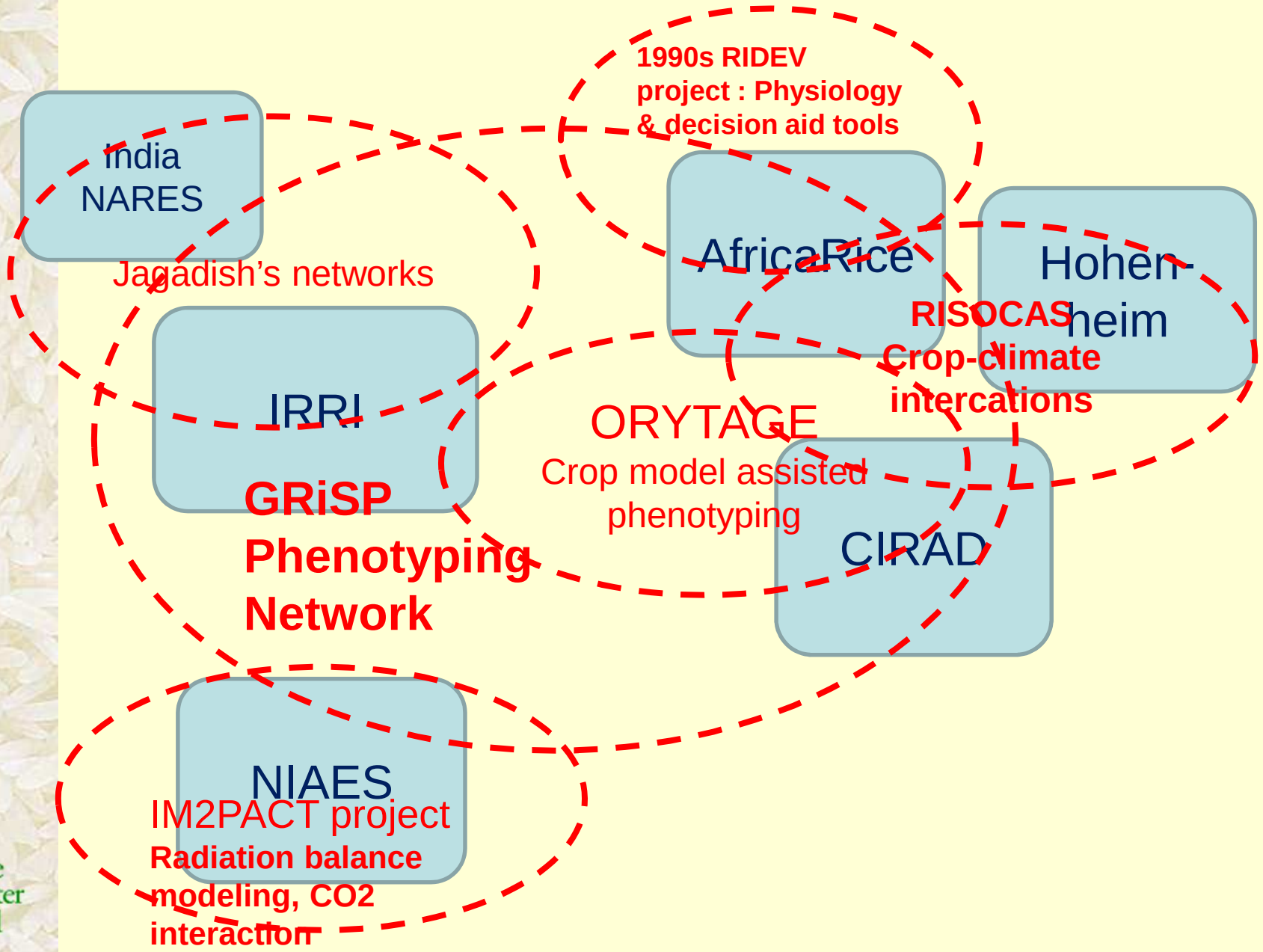
Research Landscape



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History

Sahel irrigated rice and the 1st RIDEV tool

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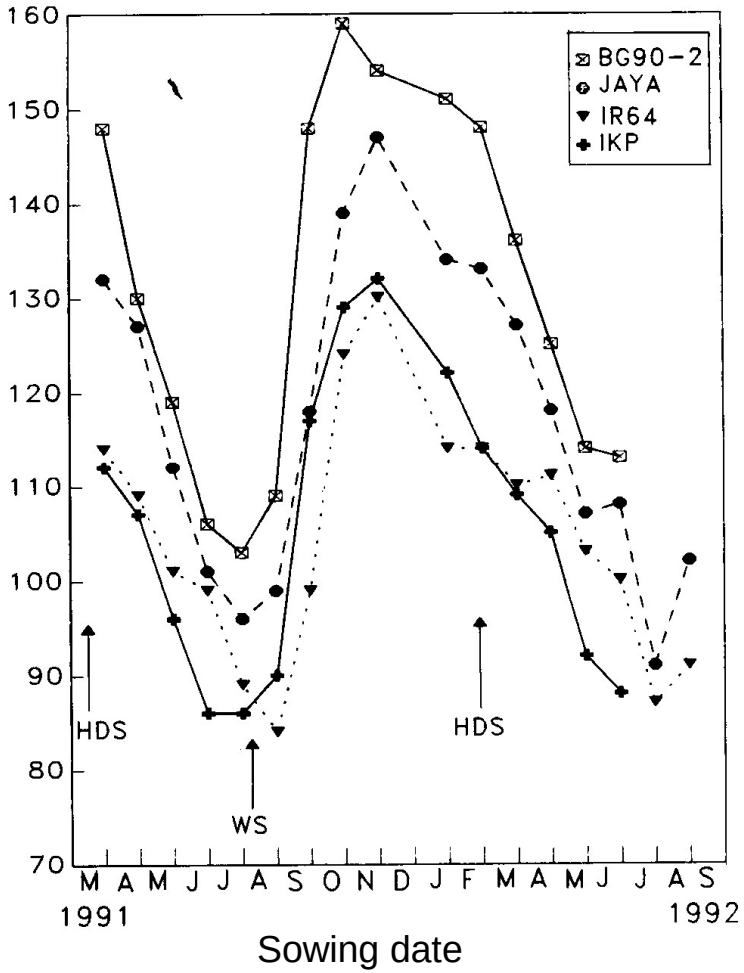
History 1 (WARDA 1990s):
Thermal constraints to irrigated rice in Senegal

Days to flowering



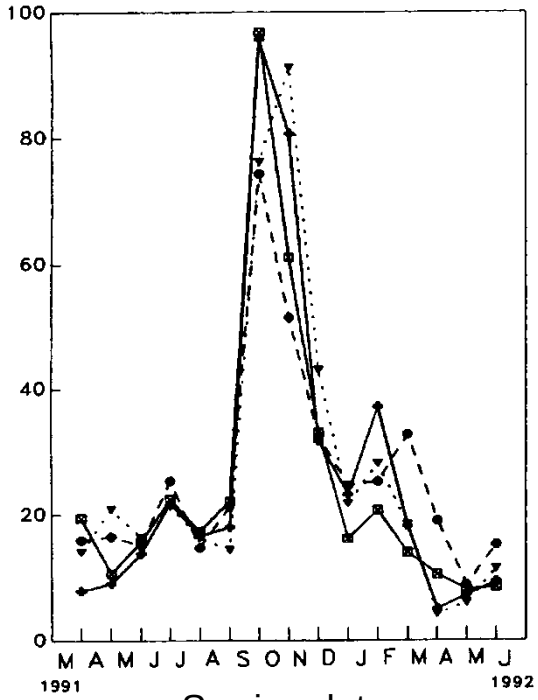
Sowing date

Sowing date vs. crop duration and sterility

⇒ **Thermal and photoperiod effects on phenology**

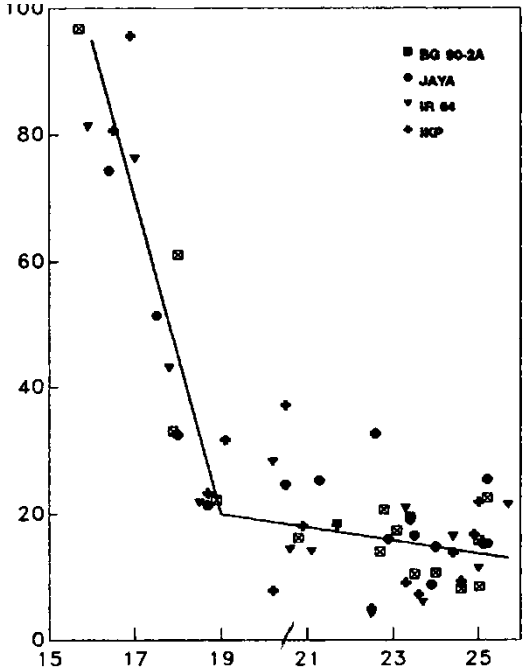
⇒ **Chilling causes spikelet sterility**

% sterility



Sowing date

% sterility



Tw(min) at booting

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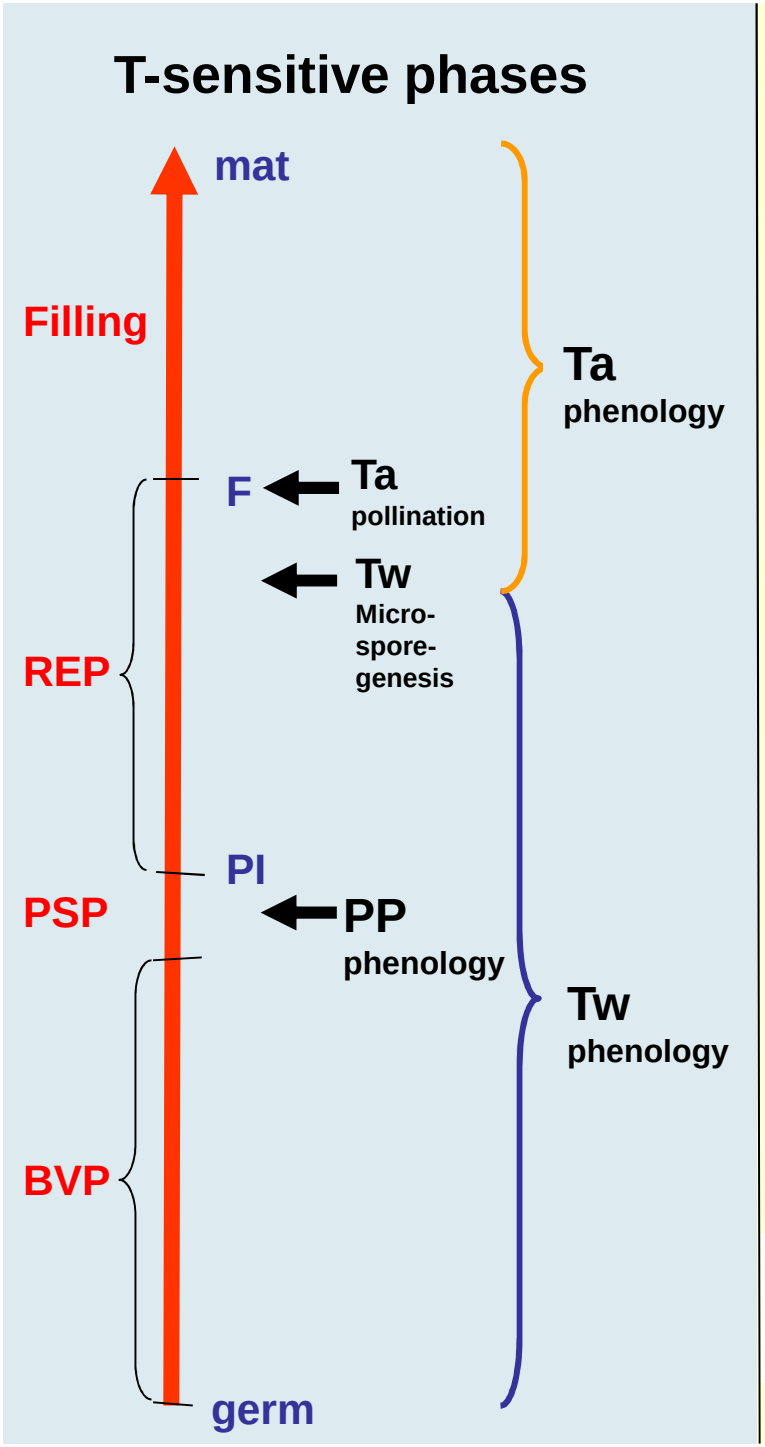
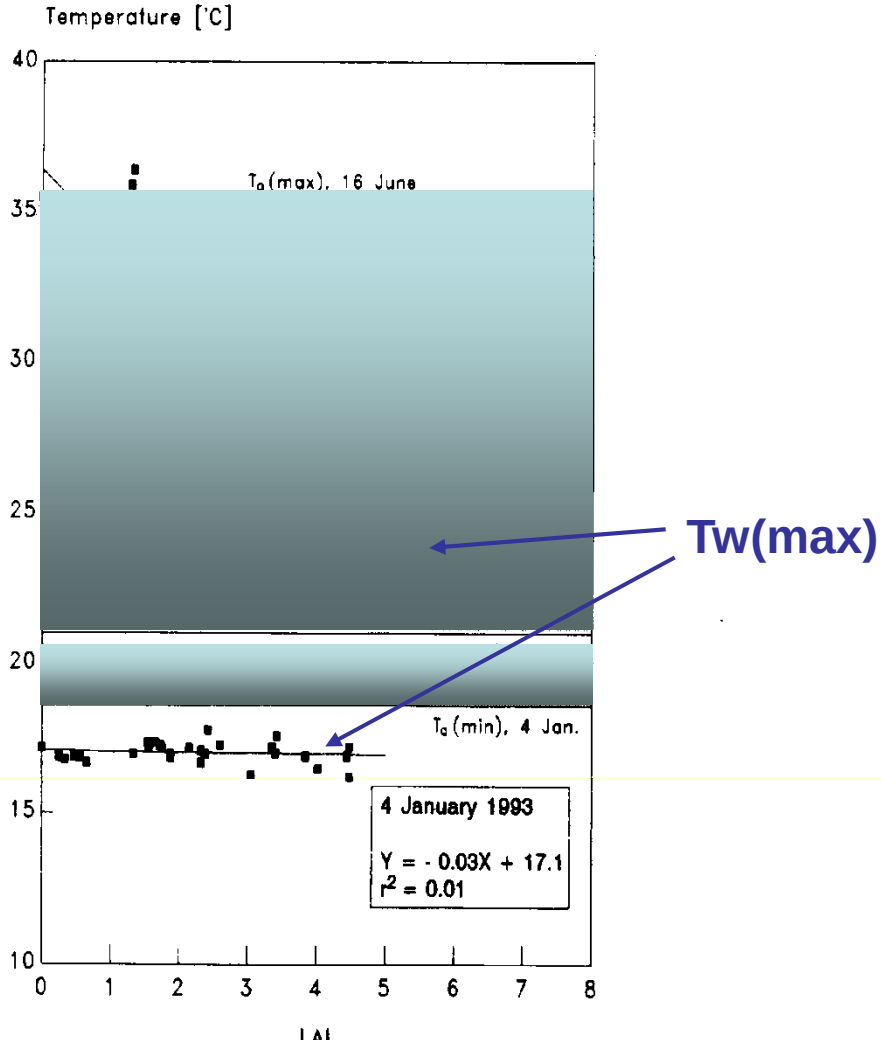
History 2: basis of 1995 RIDEV





=> Water temperature governs phenology and chilling-induced sterility in flooded rice

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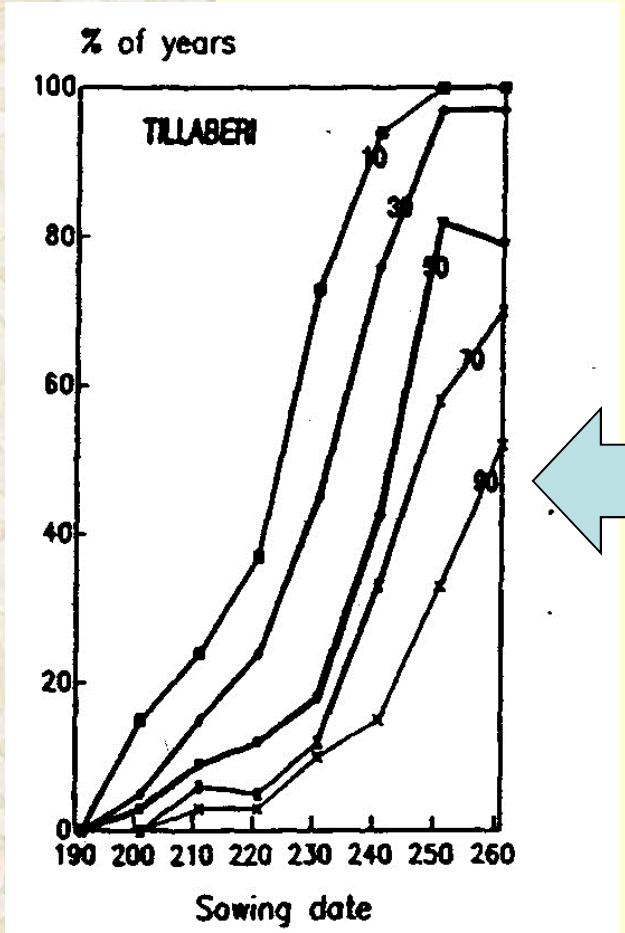
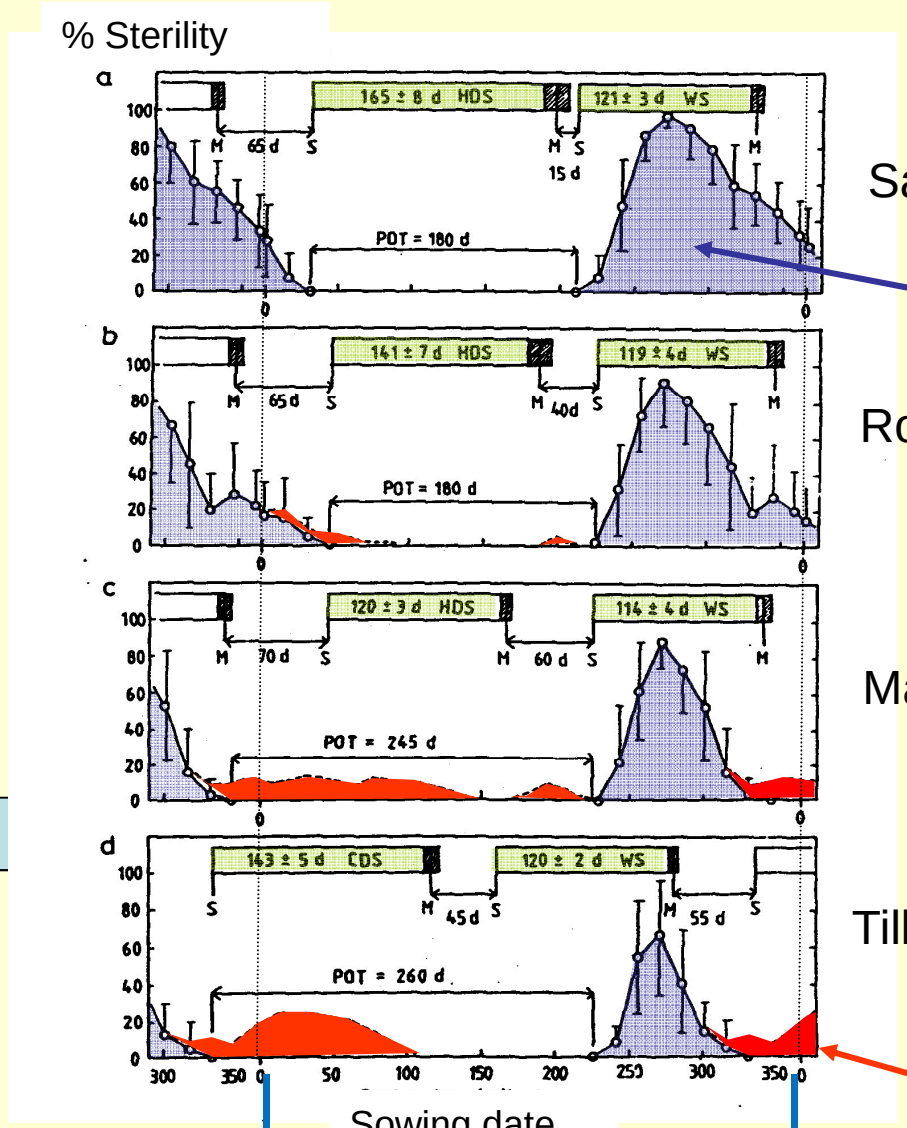
History 3: Risk analysis with RIDEV / crop calendars

Sterility probability 1950-1982





Sterility (cold)

Sterility (heat)

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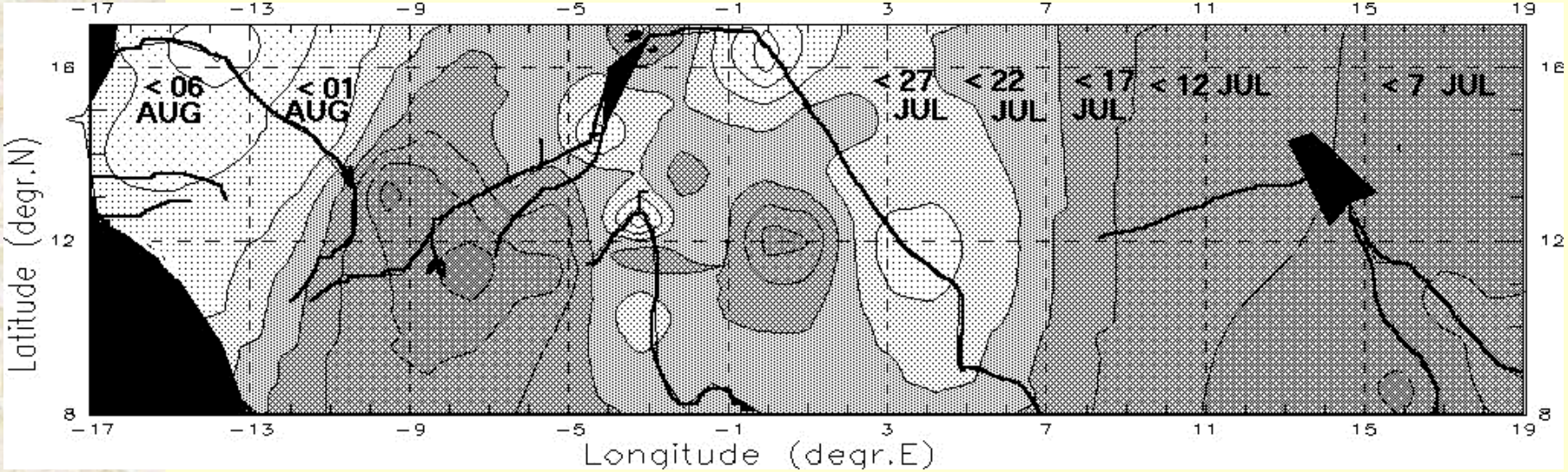
History 4: Mapping sterility risks with RIDEV

Zoning of latest possible sowing date for Sahel wet season irrigated rice crop



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New study on rice phenology and sterility responses to T

(Thesis of *Cecile Julia*)

- **Emphasis on microclimate**
  - Meristem T for phenology
  - Floodwater T for chilling stress at microspore stage
  - Panicle T for heat stress at anthesis
  - Time of day of anthesis (TOA)
- **Towards a new RIDEV**
- **Funding: GEZ (Risocas project) and ARC (modeling research at IRRI)**

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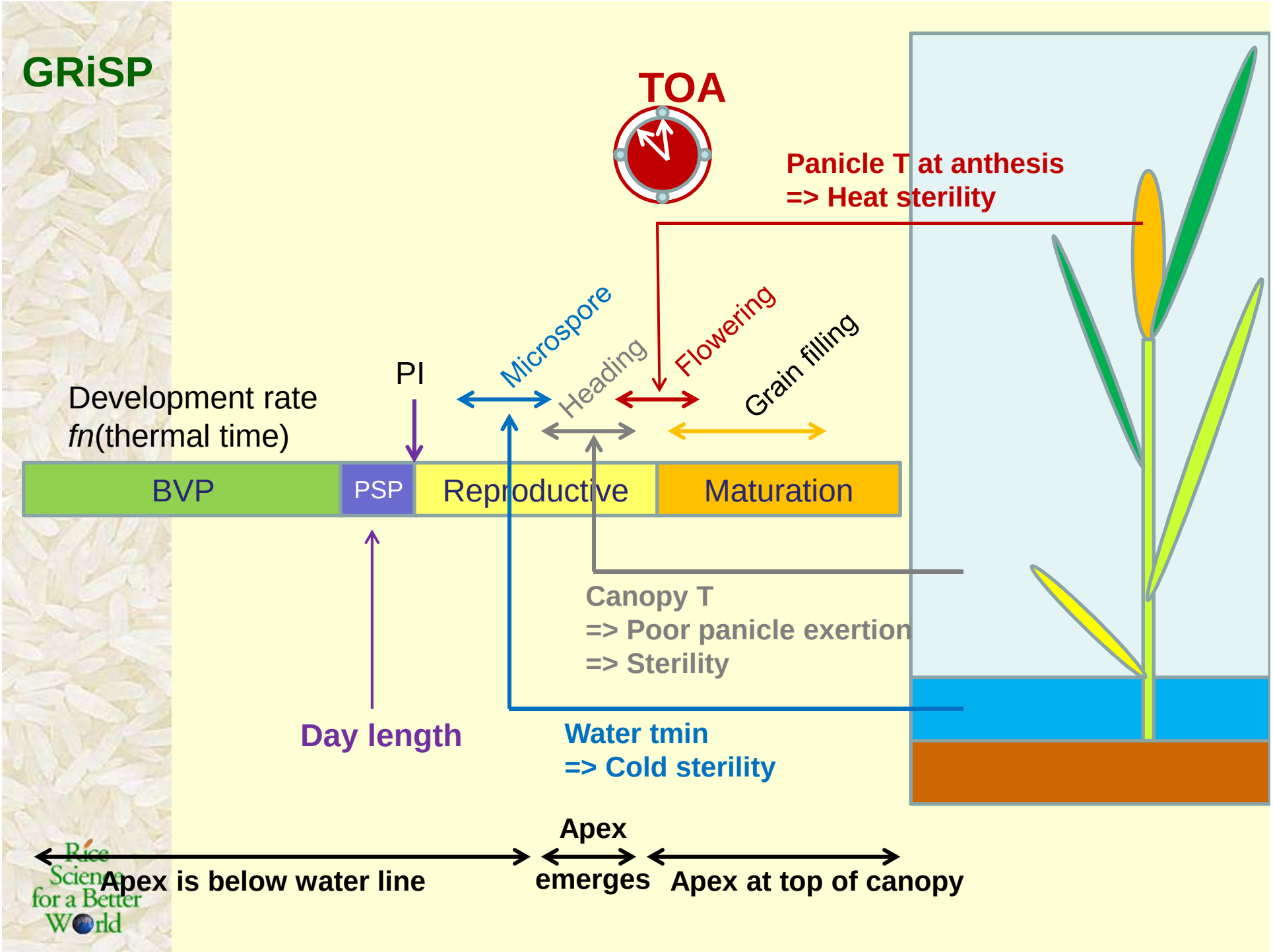

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Thesis study: (Cecile Julia)

4 genotypes

IR64
IR72
Sahel108
Chomrong
(N22 failed)

4 environments

DS Philippines
HDS Senegal
CDS Senegal
Temp. summer France

Traits observed

Phenology
TOA
Panicle Tr cooling

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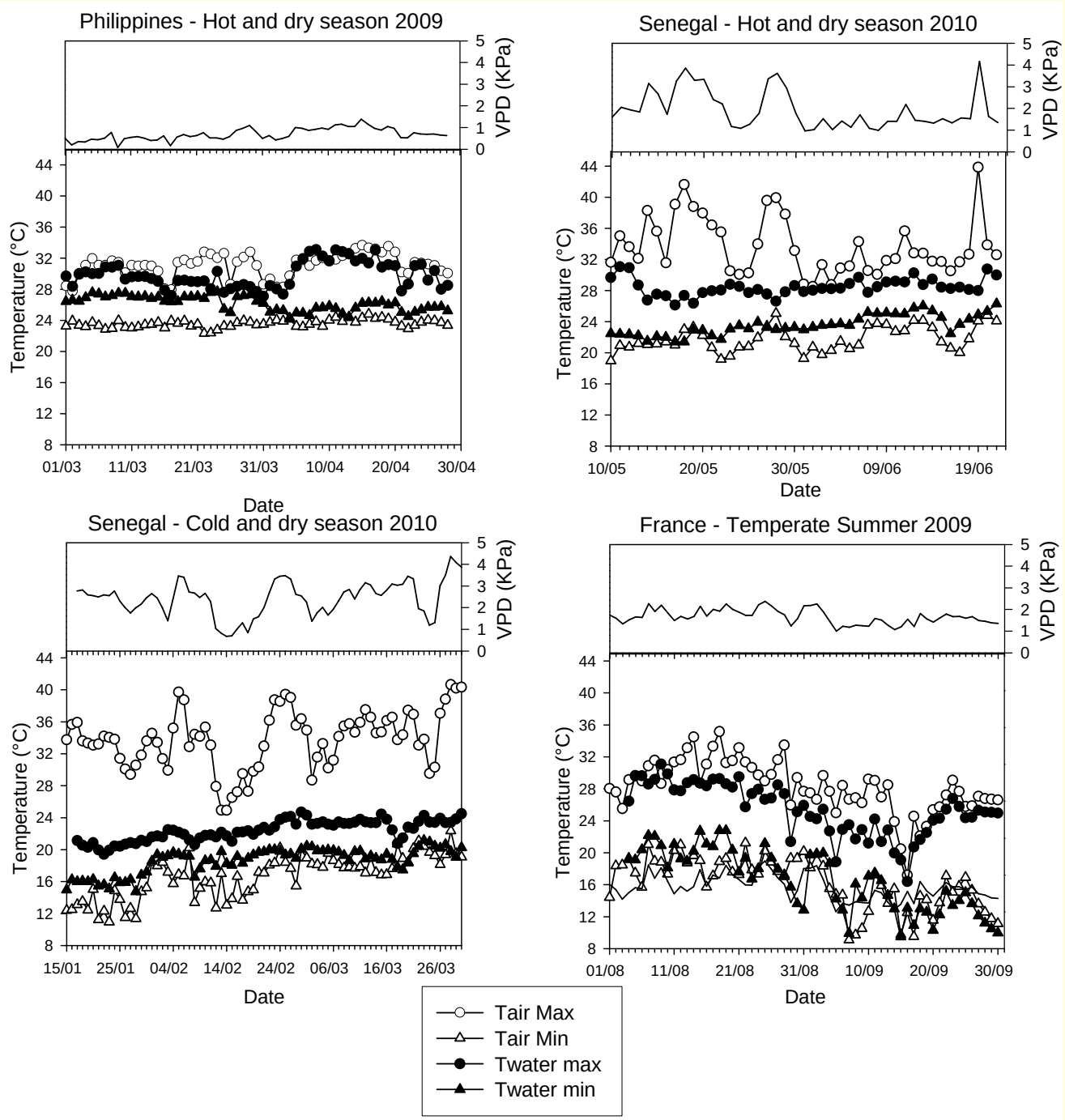

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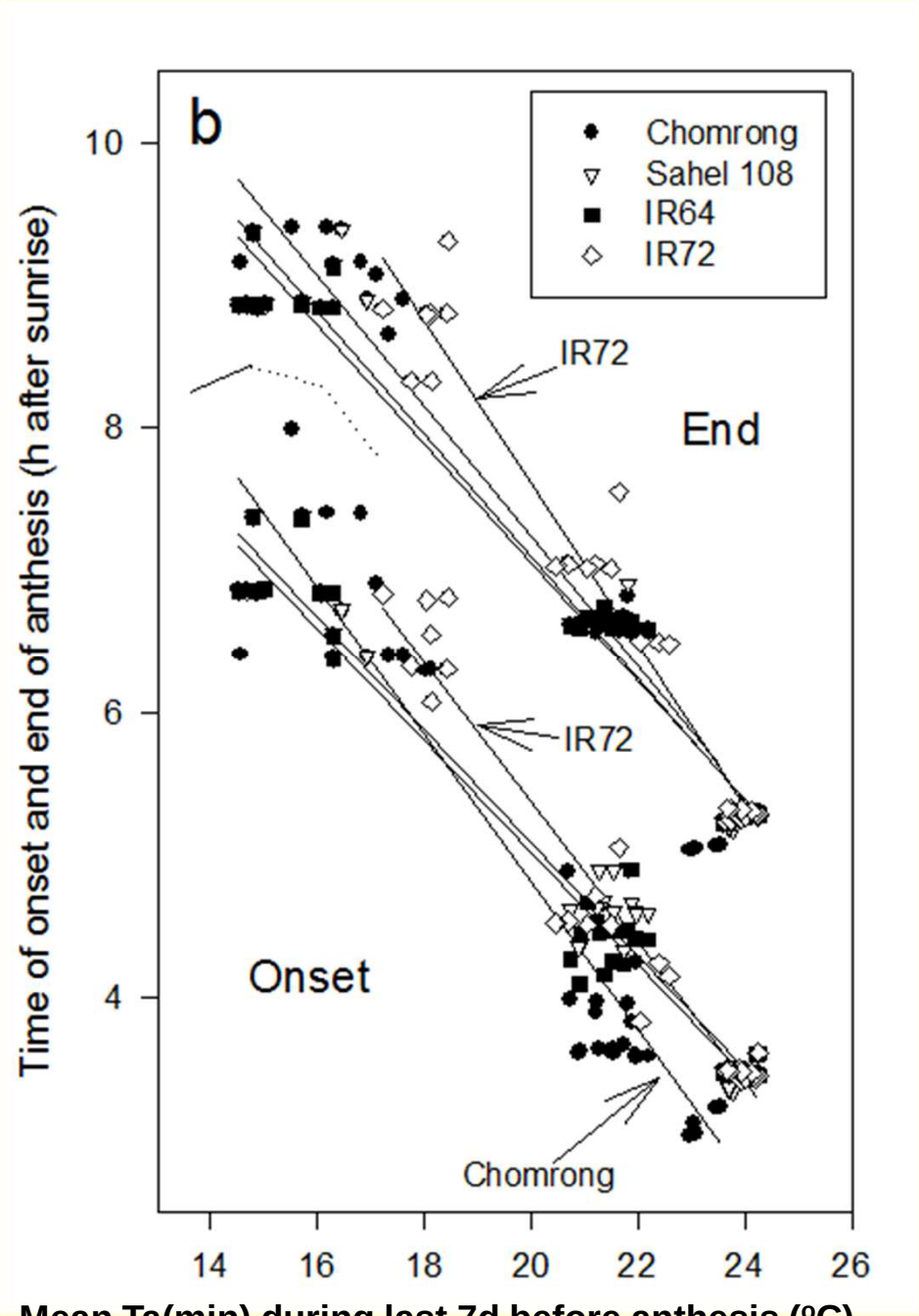
Results

Time of day of anthesis shows adaptive plasticity

Warm nights advance TOA => Escape midday heat

Humid days advance TOA => escape heat caused by absence of transpiration cooling



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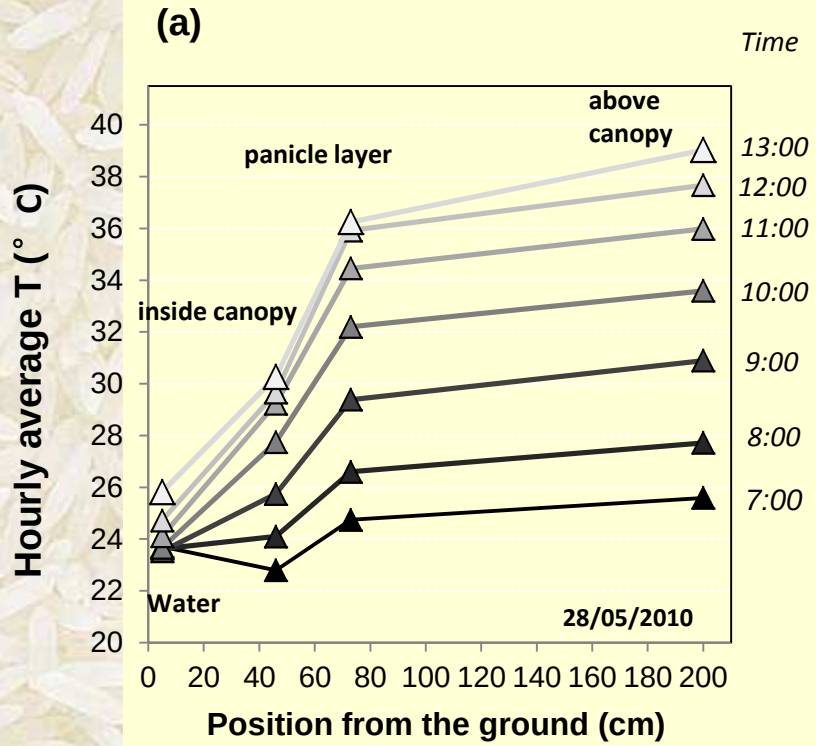
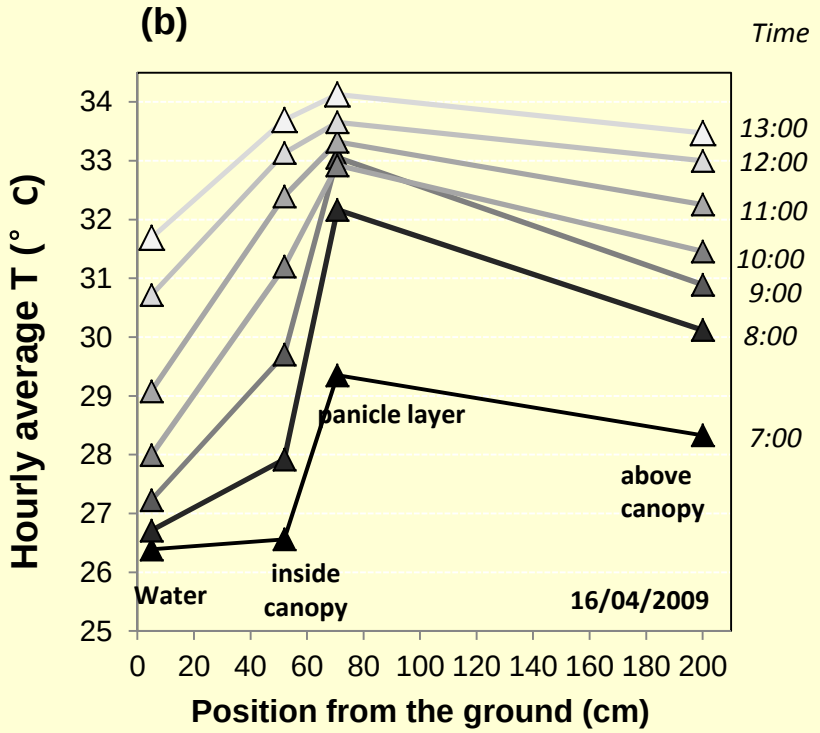
Microclimate in IR64 canopy: Examples of sunny days





Senegal, hot-dry season

Philippines, dry-season

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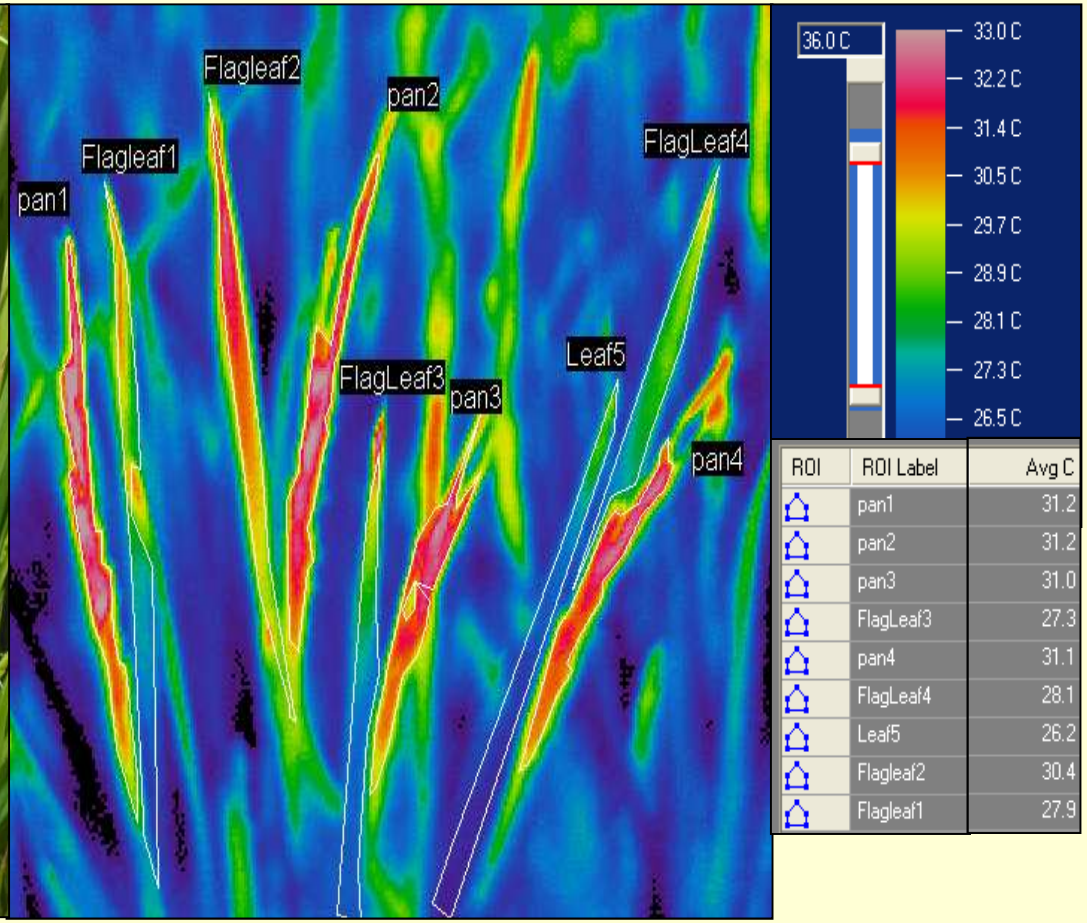
Panicle temperature



ROI	ROI Label	Avg C
	pan1	31.2
	pan2	31.2
	pan3	31.0
	FlagLeaf3	27.3
	pan4	31.1
	FlagLeaf4	28.1
	Leaf5	26.2
	Flagleaf2	30.4
	Flagleaf1	27.9

Ca. 4900 IR observations on in-situ panicle T
Microclimate recording
Agronomic observations incl. %sterility

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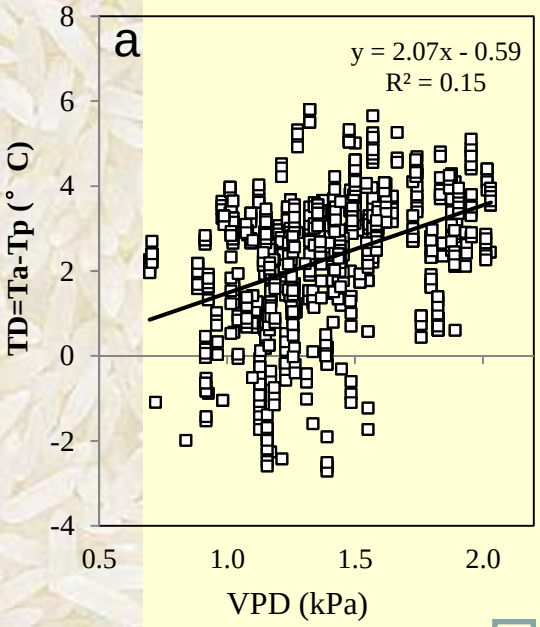
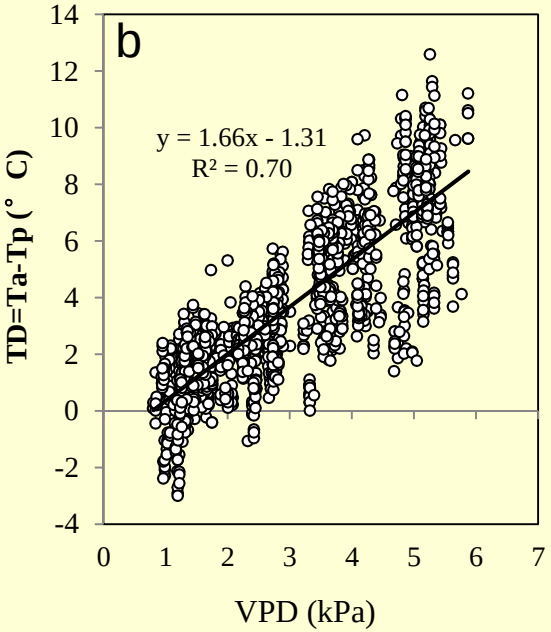
Panicle-air temperature difference

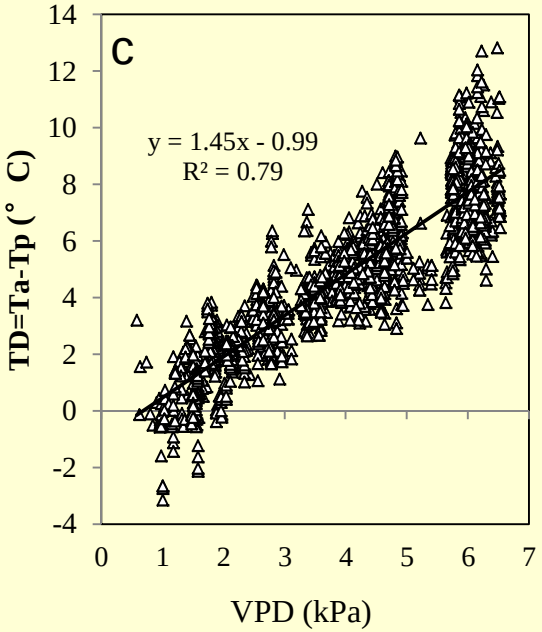
Philippines

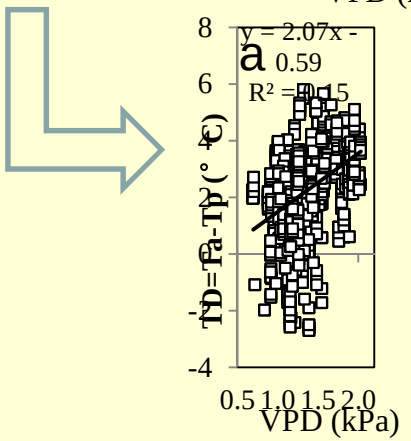


Senegal hot-dry season



Senegal cool-dry season





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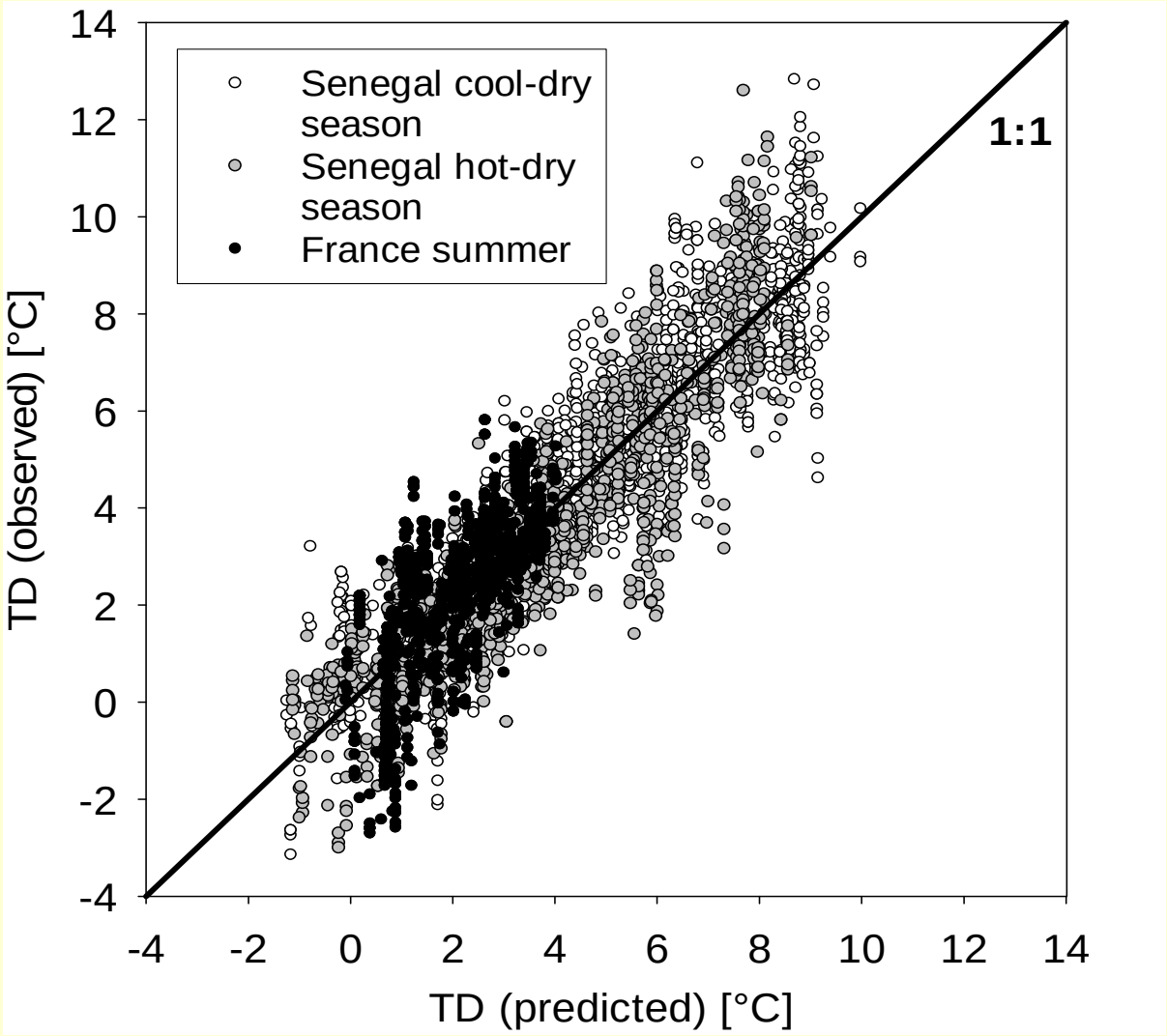
Panicle-air temperature difference (=>RIDEV): Regression model adopted for simulation



Multiple regression model predicting TD from…

VPD, Rs, Ta, Sun angle, and Panicle height from ground

TD1 = -1.578 + 1.093*__VPD__+0.189*__Tair__ - 3.367E-02*__TopP-__3.99E-03*__Rs__ + 3.31E-02*__Hdeg__

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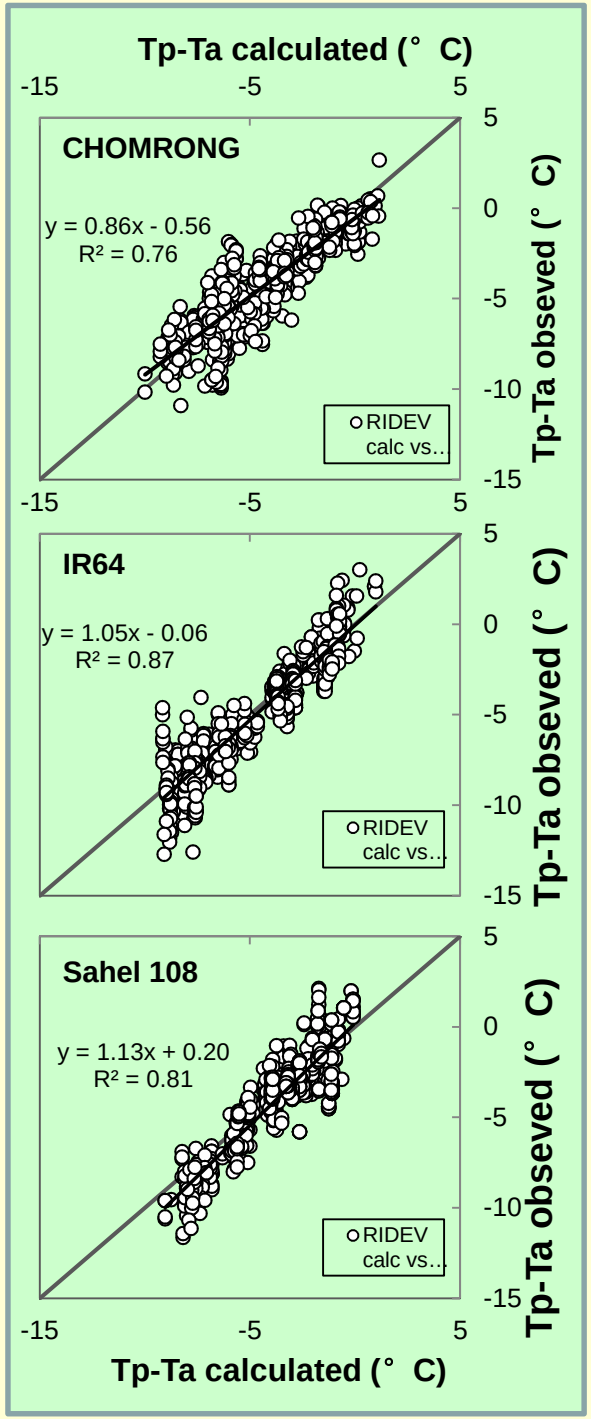
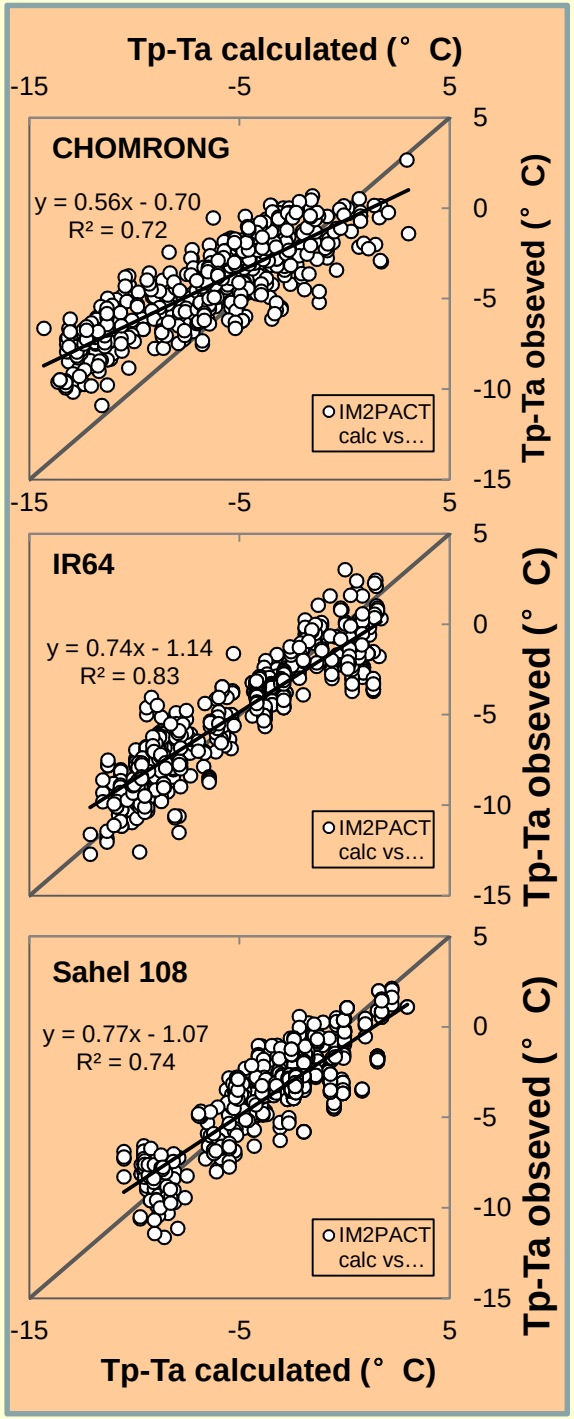
RIDEV vs. IM2PACT

(Tsukuba, field-calibrated in Japan)





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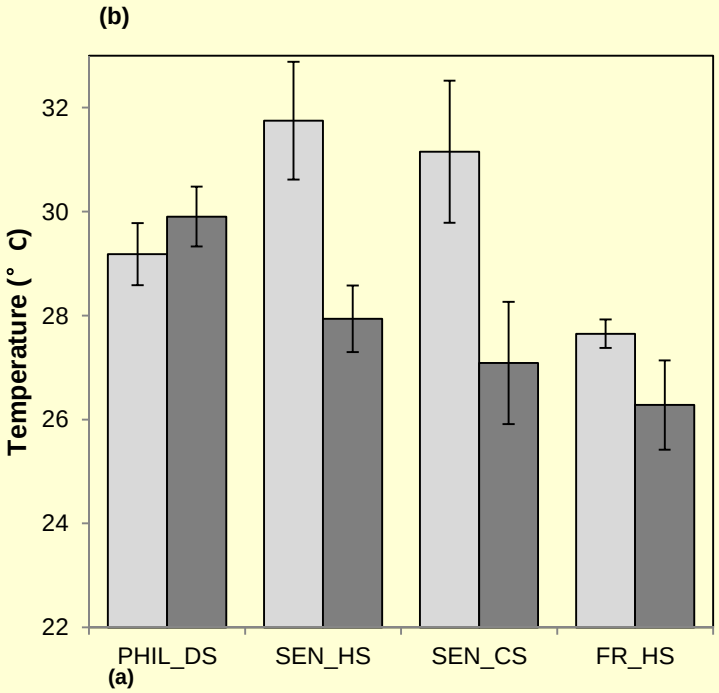
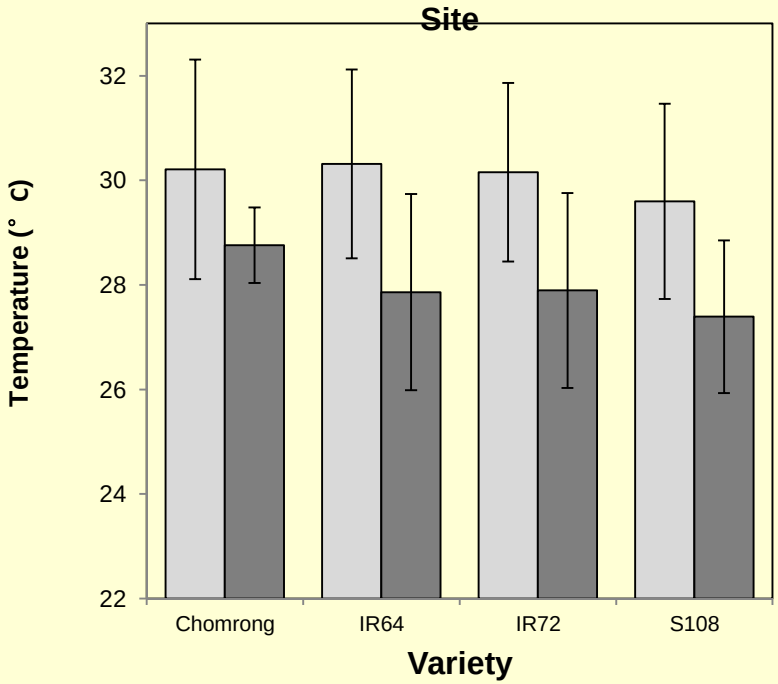
Air and Panicle Temperature at TOA (calculated)

Site means



Genotype means



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Disaggregation of observed sterility into its components

- Incomplete panicle exertion
- Chilling at microspore stage
- Heat at anthesis (TOA)

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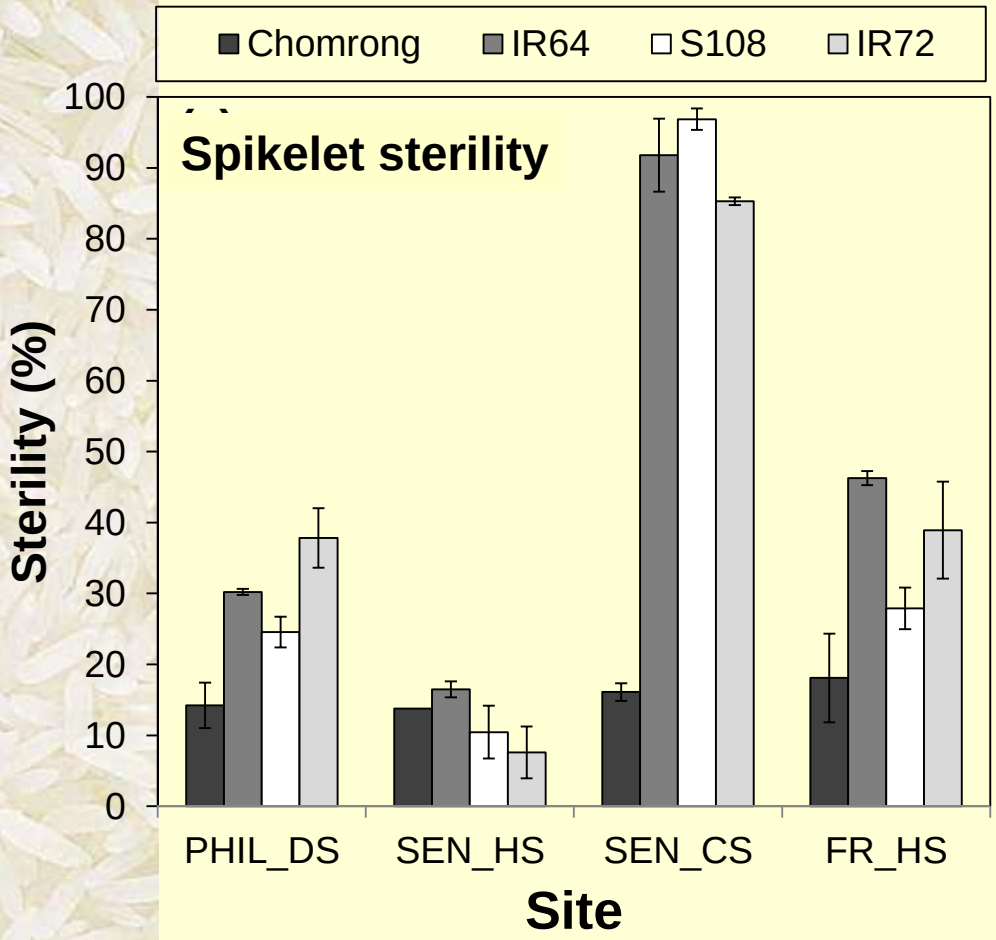
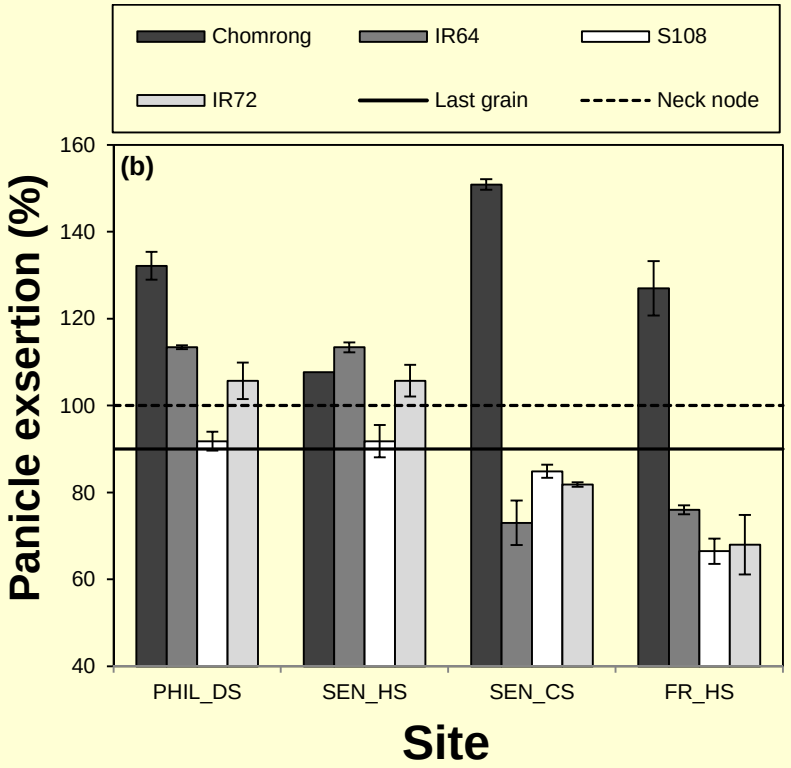
Observed spikelet sterility



Incomplete panicle exertion

- occurred in cold-night environments
- explained some of observed sterility

Panicle exertion at flowering



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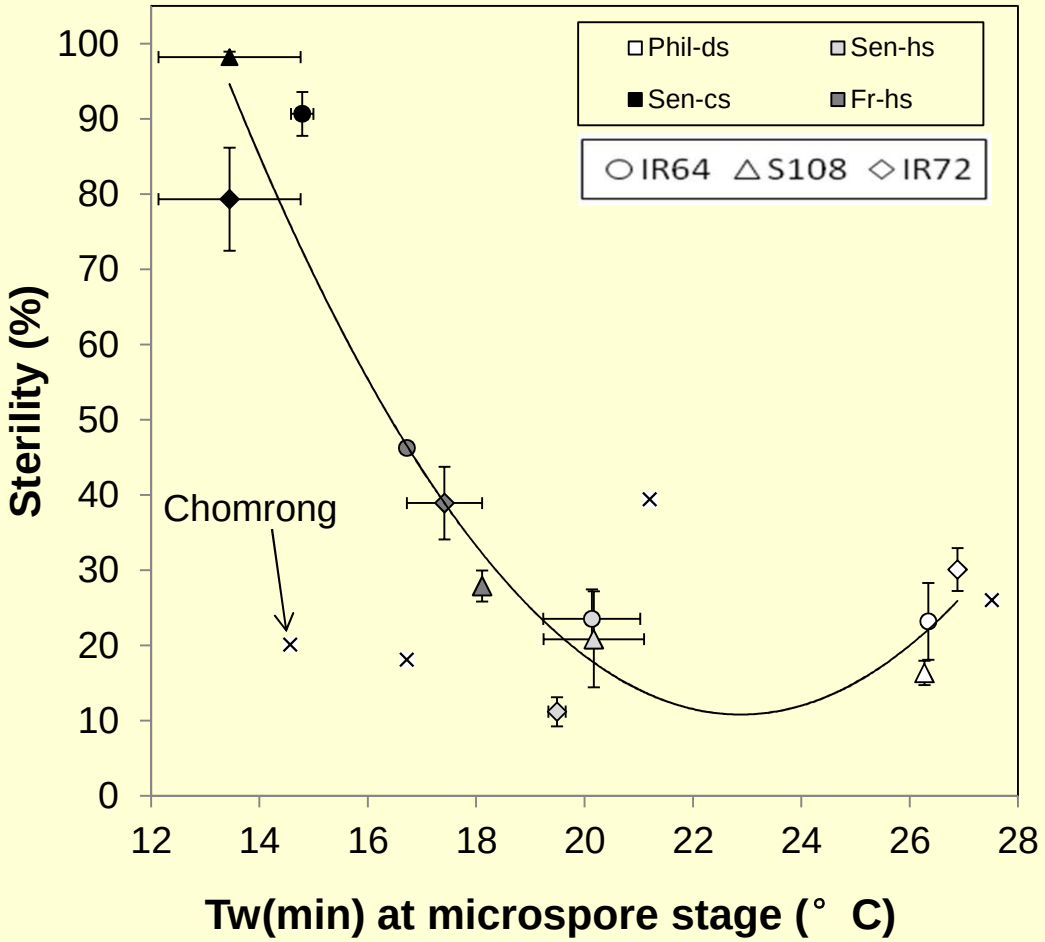
Chilling effect at microspore stage on sterility



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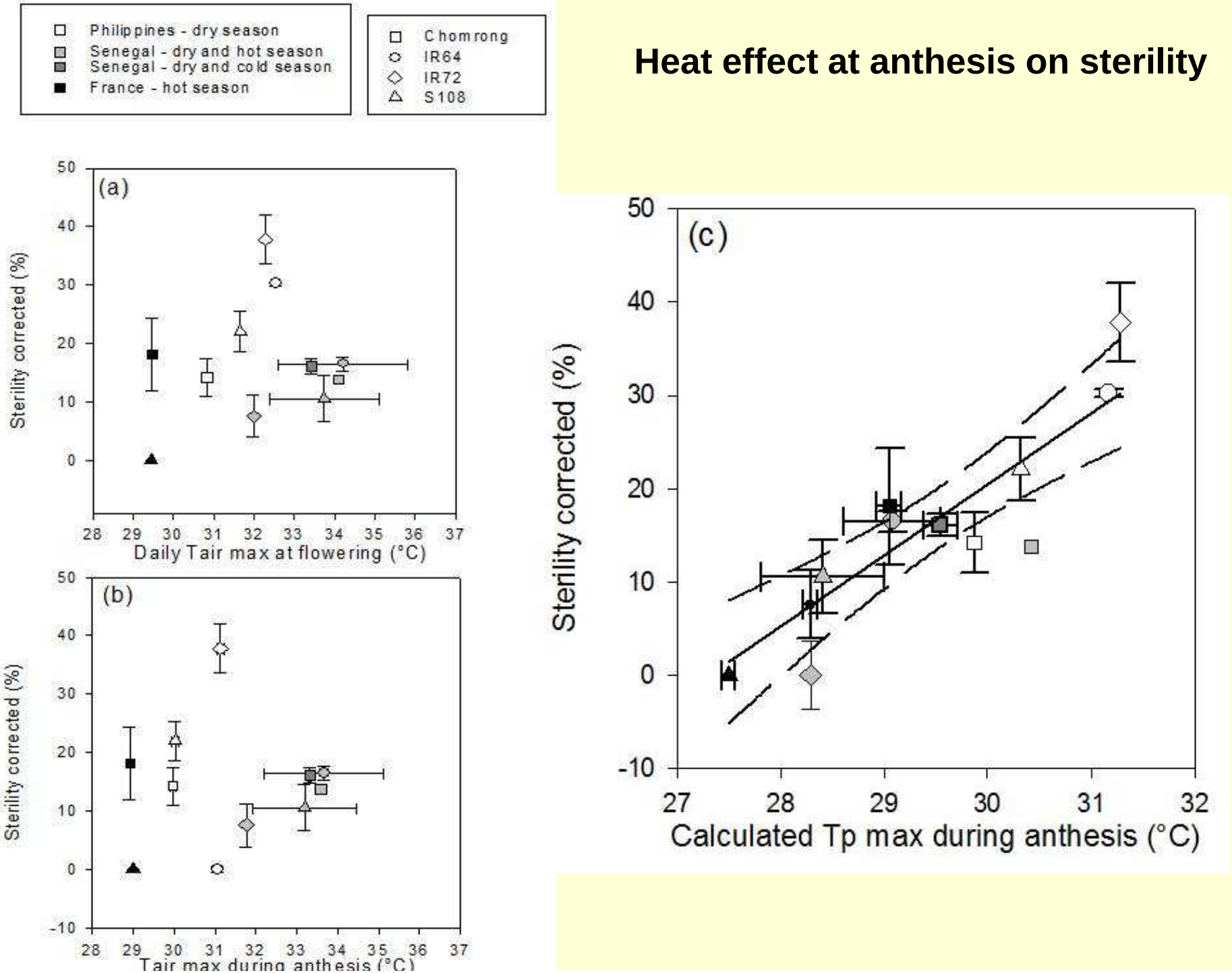
Heat effect at anthesis on sterility



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Conclusions of experimental study
(Thesis C. Julia)

Reproductive-stage adaptations to thermal stresses:

- **Tolerance**
  - **Pollen viability under heat/cold (anti-oxidants? OA? Membrane & protein properties?)**
- **Avoidance**
  - **Transpiration cooling of panicle**
  - **Good panicle exertion (long peduncle)**
- **Escape**
  - **Time of day of anthesis (TOA)**
  - **Adaptive plasticity of TOA**
  - **Temporal spread of anthesis (e.g., 2 wk)**

Heat stress more likely in warm-humid than hot-dry climates!

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Modeling with RIDEV

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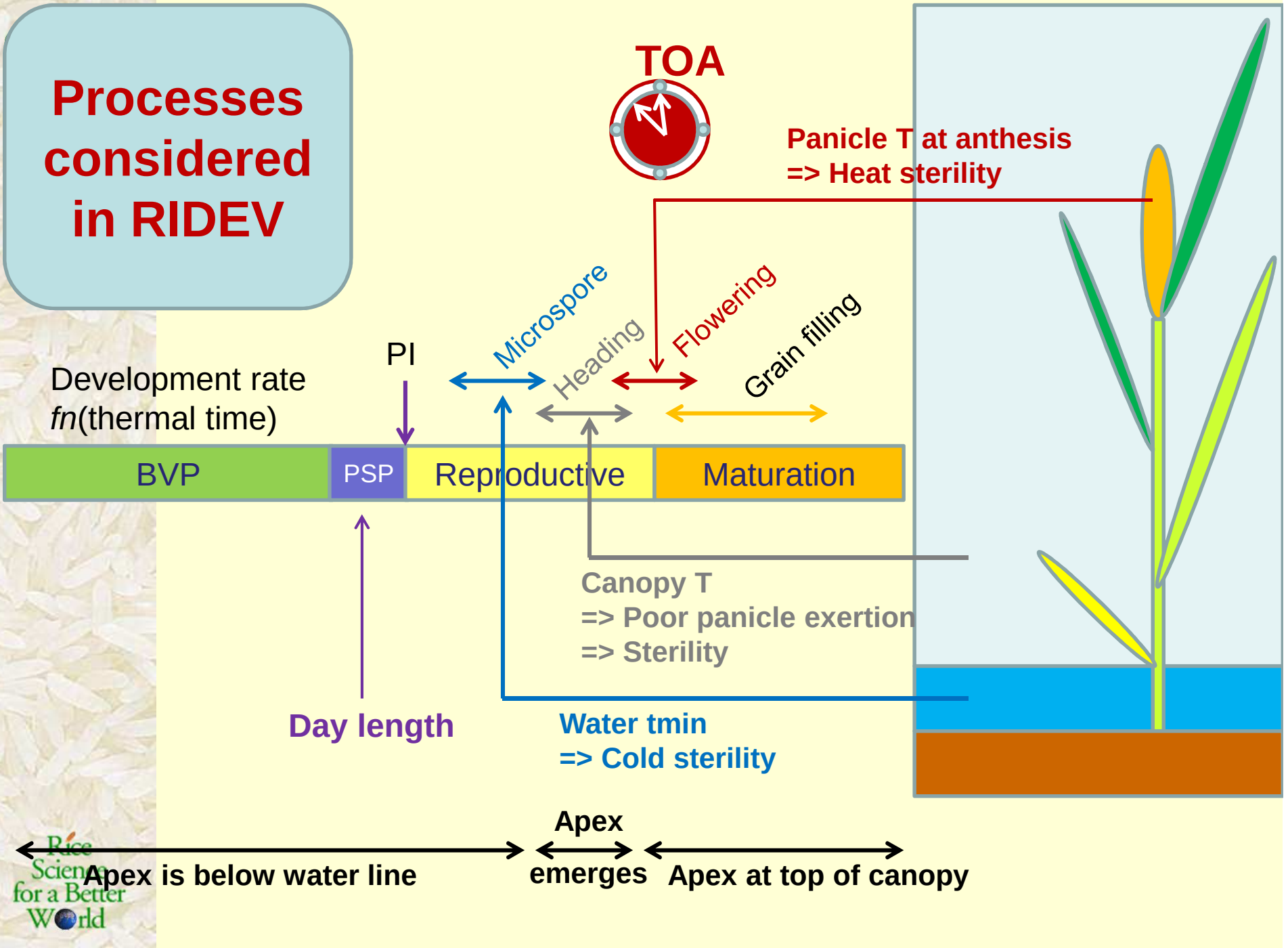
Processes considered in RIDEV



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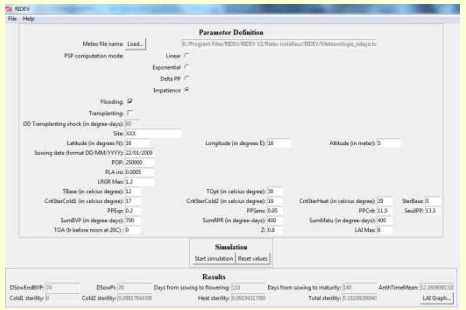
RIDEV, new tool for crop-model assisted phenomics



- **Simulator of…**
  - **Phenology incl. microclimate & PP effects**
  - **Sensitive phases to T of reproductive processes**
  - **G and E effects on TOA**
  - **Sterility caused by…**
    - Chilling effects on microsporogenesis (water Tmin)
    - Chilling effects on panicle exertion (air Tmin)
    - Heat effects on pollination (Tpanicle at anthesis)
- **Prediction (forward mode)**
  - CC impact mapping, plant type optimization
  - Agronomy (optimize genotype and crop calendar; risk studies)
- **Heuristic parameterization of genotypes (reverse mode)**
  - Phenomics (extraction of genotypic parameter values from experimental data)

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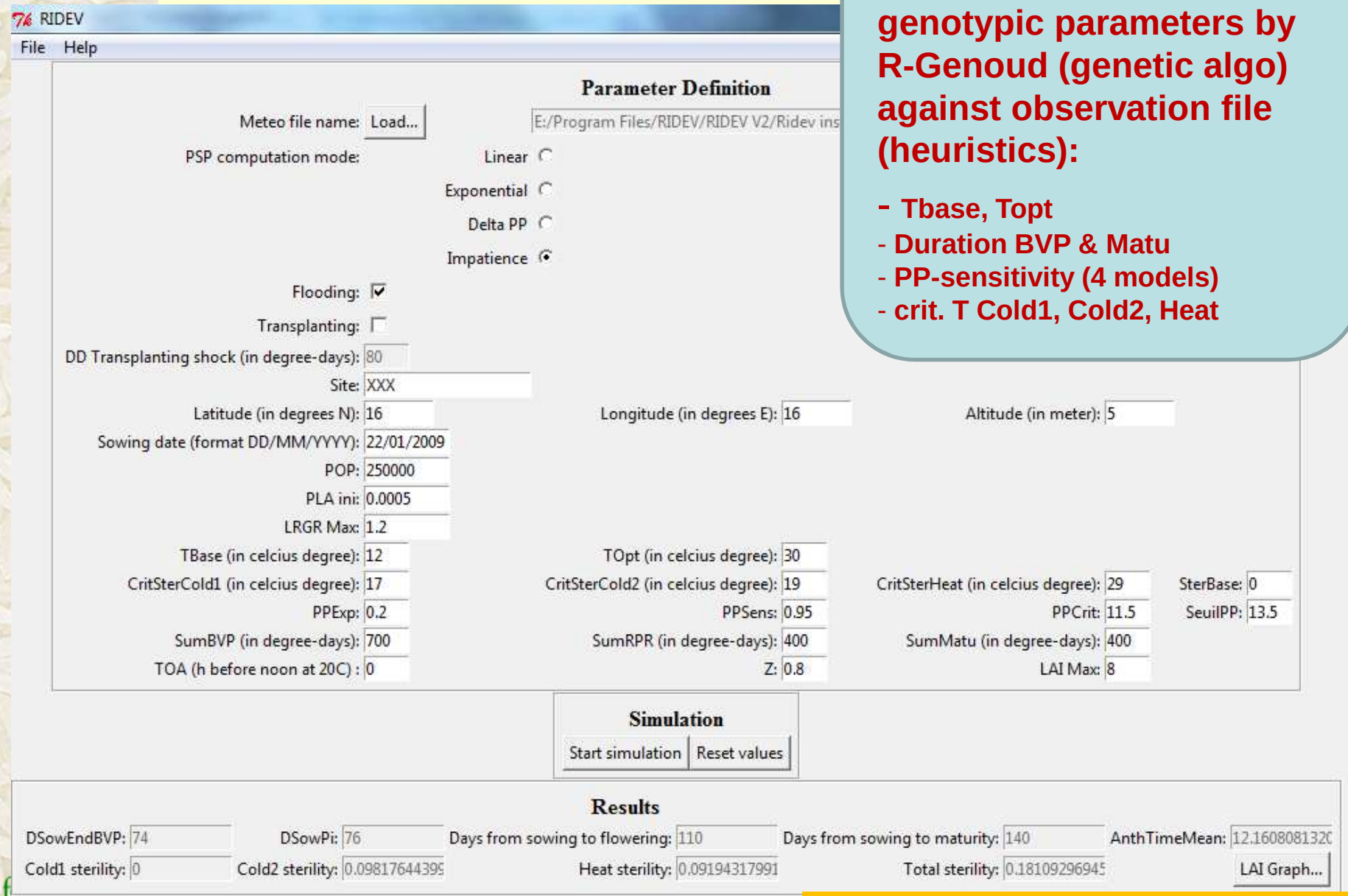
RIDEV Interface for point simulations



HTP Optimization of genotypic parameters by R-Genoud (genetic algo) against observation file (heuristics):

- **Tbase, Topt**
- **Duration BVP & Matu**
- **PP-sensitivity (4 models)**
- **crit. T Cold1, Cold2, Heat**

Programming languages: C++, R

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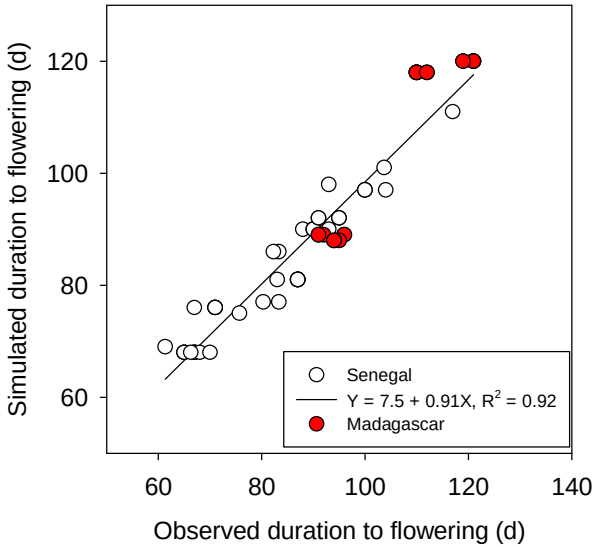
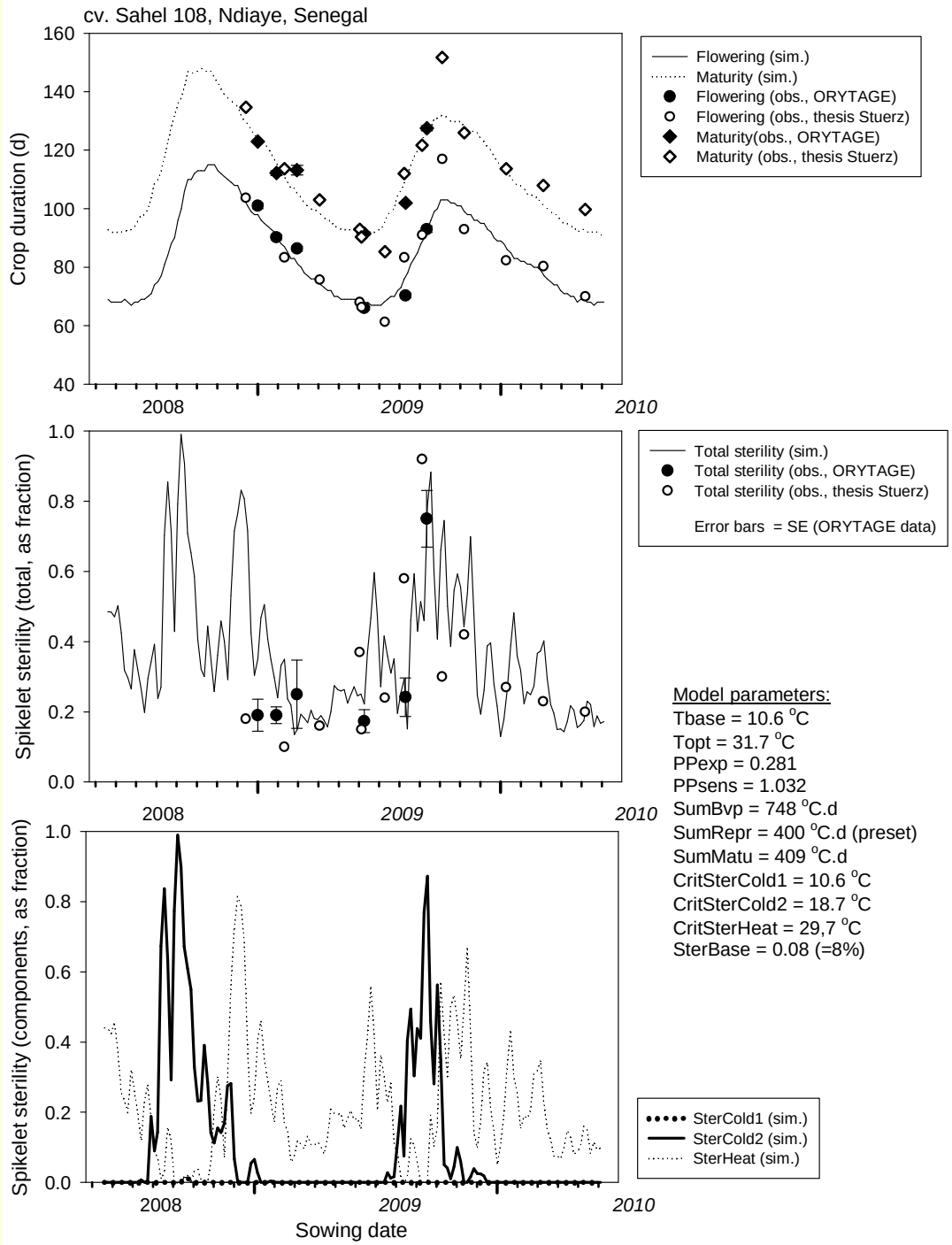
Example of fitting RIDEV

-SAHEL 108
- Many sowing dates
- Different data sources

BUT: still problems with fitting some trad. cvs.





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Issues

- **Methodological (RIDEV)**
  - Phenology of some traditional cvs. is difficult to simulate (complex T x PP interaction?)
  - More validation needed before extrapolation
- **New scientific questions**
  - Trade-offs between water-saving and transpiration cooling (extend RIDEV to water limited situations)
  - Transpiration cooling under high CO2?
  - Genetics of heat avoidance (transpiration cooling) and escape (adaptive plasticity of TOA)

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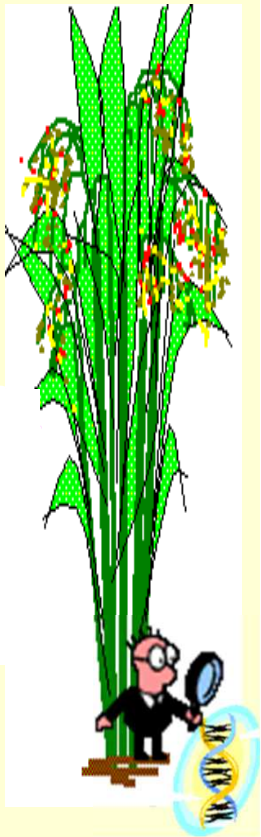
Outlook (1)
Use of RIDEV for Phenomics/GWAS

- **Indica GWAS panel (200 acc., ORYTAGE project)**
- **Field-phenotyped for phenology and sterility in 12 environments:**
  - 6 sowing dates in Senegal
  - 3 altitudes x 2 years in Madagascar
- **Extraction of genotypic response parameters across environments:**
  - Cardinal temperatures Tb and To
  - Thermal duration of phenological phases
  - PP-sensitivity
  - Chilling sensitivity of microsporogenesis
  - Chilling sensitivity of panicle exertion
  - Heat sensitivity of anthesis
- **Association study using 700K Oryza SNP chip**



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APO
ASD 1
AZUCENA
BASMATI 370
BULU PANDAK
DOM SOFID
DULAR
FANDRAPOTSY 104
FR13A
WAS 33 B-B
GIZA 171
IAC 165
IR64
KAUKKYI ANI
KHAO DAM
KHAO DAWK MALI 105
M 202
MOROBEREKAN
N 22
NIPPONBARE
TEQUING

Chromrong
SAHEL 201

Oryza SNP panel (all genetic groups)

91-385	DA5	JAMAJIGI	PA TOU HUNG	TAICHUNG NATIVE 1	WAB 706-3-4-K4-KB-1
93-11	DA9	JC120	PAPPAKU	TAMCAU 9 A	WAS105-B-IDSA-B-WAS2-1-FKR-1
ADNY 11	DANAU LAUT TAWAR	JC91	PATIK	TELIMANI	WAS169-B-B-4-2-1
AI CHIAO HONG	DE ABRIL			OLANA 177	WAS170-B-B-1-1
ANGIFOTSY 685	DHOLA AMAN				WAS173-B-B-6-2-2
APURA	DOURADO A			NIYA	WAS174-B-3-5
ARANG	DR92			ANDE	WAS181-B-6-3
B2997C-TB-4-2-2-1	FEDEARROZ			NY 663	WAS182-B-1-1
B6144-MR-6-0-0	FEDEARROZ			NY 669	WAS183-B-6-2-3
BADKALAMKATI	GAJPATI				WAS194-B-3-2-5
BAGUAMON 14	GAMBIAKA K			231	WAS197-B-6-3-11
BALA	GIE 57			160	WAS198-B-3-1-3
BENGALY 389	GOCHI BORO			OTSY 1883	WAS199-B-1-2-1
BETSILAIZINA	GOPAL			ENA 626	WAS200-B-B-1-1-1
BG90-2	GUAN YIN TS				WAS202-B-B-1-1-2
BH2	GWA NGASEIN				WAS203-B-B-2-4-1
BODOMANO	H15-23-DA	LAL AMAN	RAY NABJA	VANDANA	WAS206-B-B-2-2-1
BOTOHAVANA 139	HASAN SERAI	LATSIBOZAKA-112-1	ROJOFOTSY 693	VARY LAVA DE MAROVATO	WAS207-B-B-3-1-1
BOTOHAVANA B13	IM 16	LOHAMBITRO 224	ROJOKELY	VARY MADINIKA 3494	WAS208-B-B-5-1-1-3
BOTRA MAITSO	IR1561-228-3-3	MACAN BINUNDOK	ROJOMENA 1034	VARY VATO 154	WAS20-B-B-1-2-2
BOTRIKELY	IR19746-28-2-2	MADINIKA 1329	ROJOMENA B48	VARY VATO 462	WAS21-B-B-20-4-3-3
BOTRY 731	IR20	MAKALIOKA 34	RTS 12	VATO MATSOAMALONA	WAS30-11-4-6-2-2-1
BOUAKE 189	IR2006-P12-12-2-2	MALADY	RTS 14	ZALCHA	WAS33-B-B-15-1-4-5
BR24	IR22	MAMORIAKA 114	RTS 4	ARC15872	WAS49-B-B-9-1-4-2
C21	IR2307-247-2-2-3	MANGAVAVA FOTSILANSTSIKA 1177	RTS 5	ELONI	WAS50-B-B-24-4-2-1
C4 63G	IR2344-P1PB-9-3-2B	MENAHODITRA 1234	S 624	WASSA	WAS55-B-B-2-1-2-5
CARREON	IR28	MTU 9	SAHEL 108	WAY REREM	WAS57-B-B-3-1-4-6
CERE AIR	IR36	NAM ROO	SAHEL 159		WAS62-B-B-17-1-1-3
CHAU	IR5	NAM SA GUI 19	SAHELIKA		WAS63-22-5-9-10-1
CHERIVIRUPPU	IR50	NGAJA	SALUMPIKIT		
CHIEM CHANH	IR52	NIONOKA	SAMBALA MALO		
CHITRAJ	IR53236-275-1	NONA BOKRA	SAO		
CICA 8	IR55411-50	O LUEN CHEUNG	SATHI34-36		
CT6510-24-1-2	IR55419-04	ORYZICA LLANOS 5	SEBERANG MR77		
	IR57920-AC-25-2-B	ORYZICA SABANA 10	SEBOTA 65		
	IR57924-24		SHAI KUH		
	IR60		SHORT GRAIN		
	IR62266-42-6-2		SINNA SITHIRA KALI		
	IR72		SINTANE DIOFOR		
	IR74371-54-1-1		SOMCAU 70 A		
	IR8		SOMIZY		
			SONA		
			SWARNA		

A rich phenomics resource available for phenoloy & sterility:

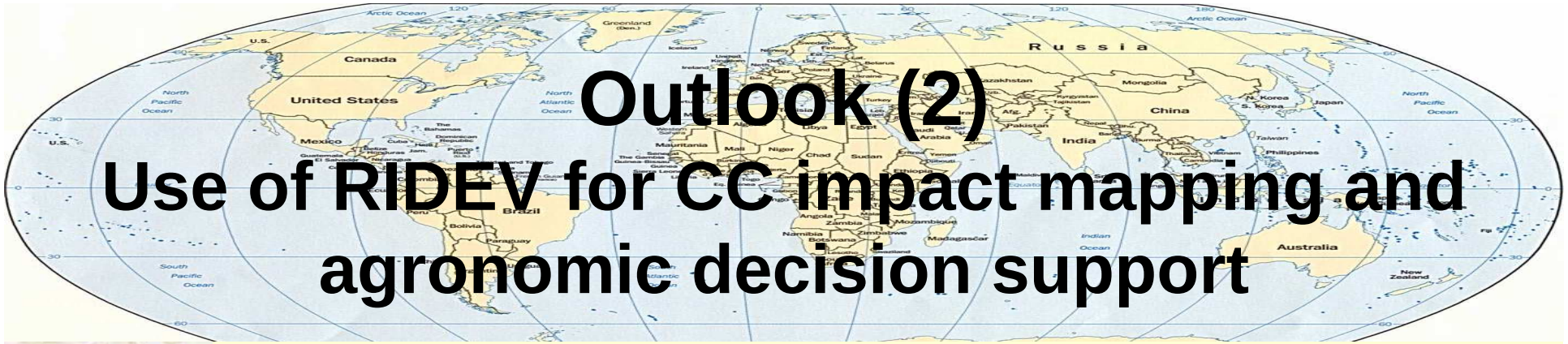
- Madagascar: 3 altitudes x 2 yrs
-Senegal: 6 sowing dates

⇒ RIDEV para optimization
⇒ GWAS

IRRI cvs

ARC cvs.

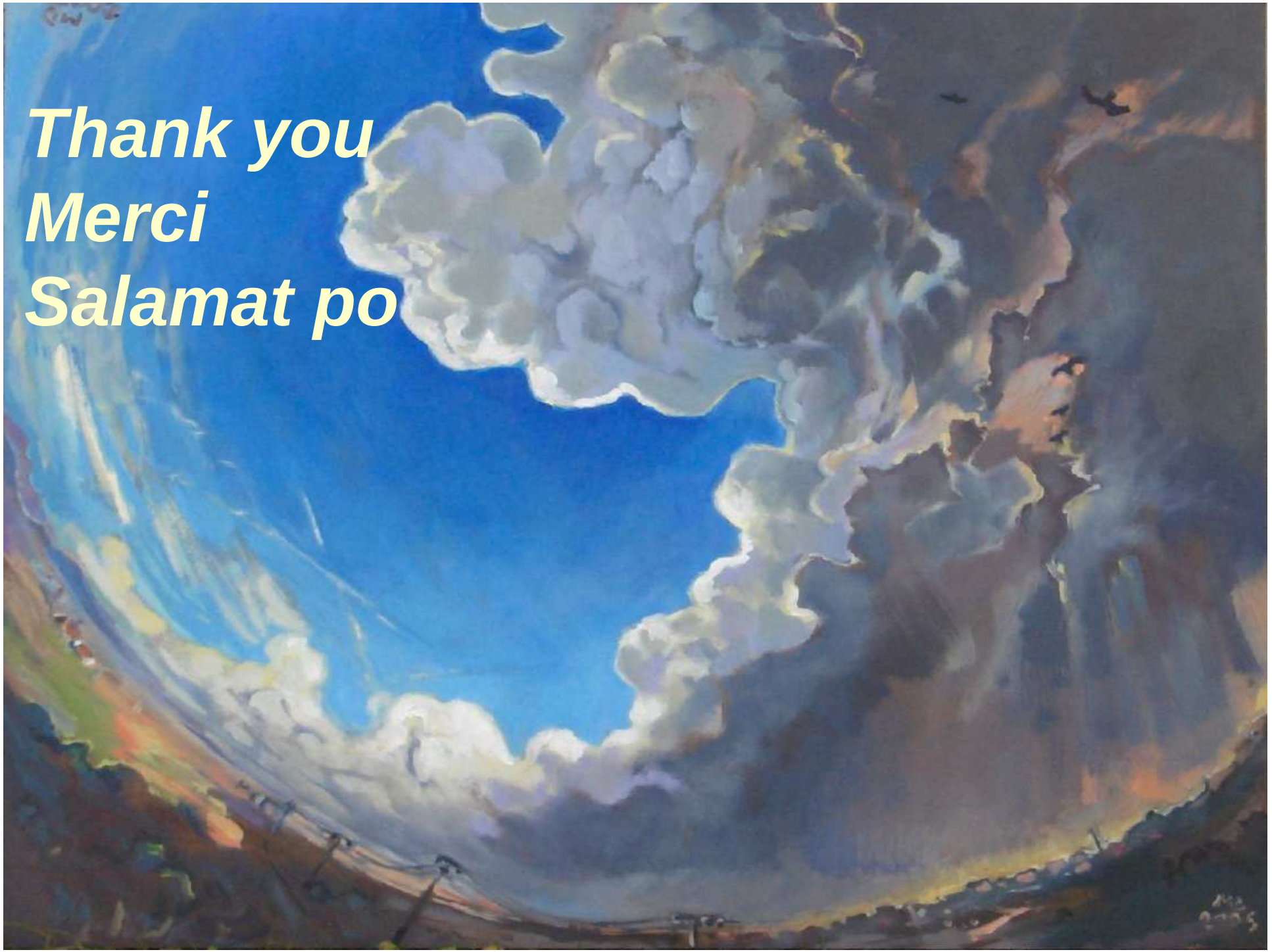
Indica panel (200)



Outlook (2)
Use of RIDEV for CC impact mapping and agronomic decision support

- Joint global mapping of thermal risks with IRRI's GIS group (A Nelson)
- CCAFS collaboration: Future climate scenarios
- RIDEV incorporation into Rice Manager for Africa

Rice Science for a Better World


Thank you
Merci
Salamat po