Climatic explanations for main season cocoa production anomalies in Cote d'Ivoire

Matthew Jones[1], Clare Stirling[2], Kassin Emmanuel[2] and Niels Anten[1]

[1]Centre for Crop Systems Analysis, Wageningen University and Research

[2]Mondelez International

matthew.jones@wur.nl

Mondelēz International

CocoaSoils Forum, Abidjan

March 2024

WAGENINGEN UNIVERSITY & RESEARCH

Context

- Dec 2023: “Main season production in Cote d’Ivoire is 35% lower than last year! What happened?”

Tuesday, March 19, 2024: Research-for-Development (R4D) Day

Venue: Silver Moon Hotel

Theme: The Future of Cocoa: Deep Learning and Facing Up to A Changing Landscape

A changing landscape (conditions/demands):

- Climate change, crashes in production and soaring prices
- Net zero carbon production systems
- Profitable and stable yields
- Regenerative agriculture and soil health
- Deforestation and the EU regulation
- Increased biodiversity and ecosystem services
- No child labour
- Gender equality

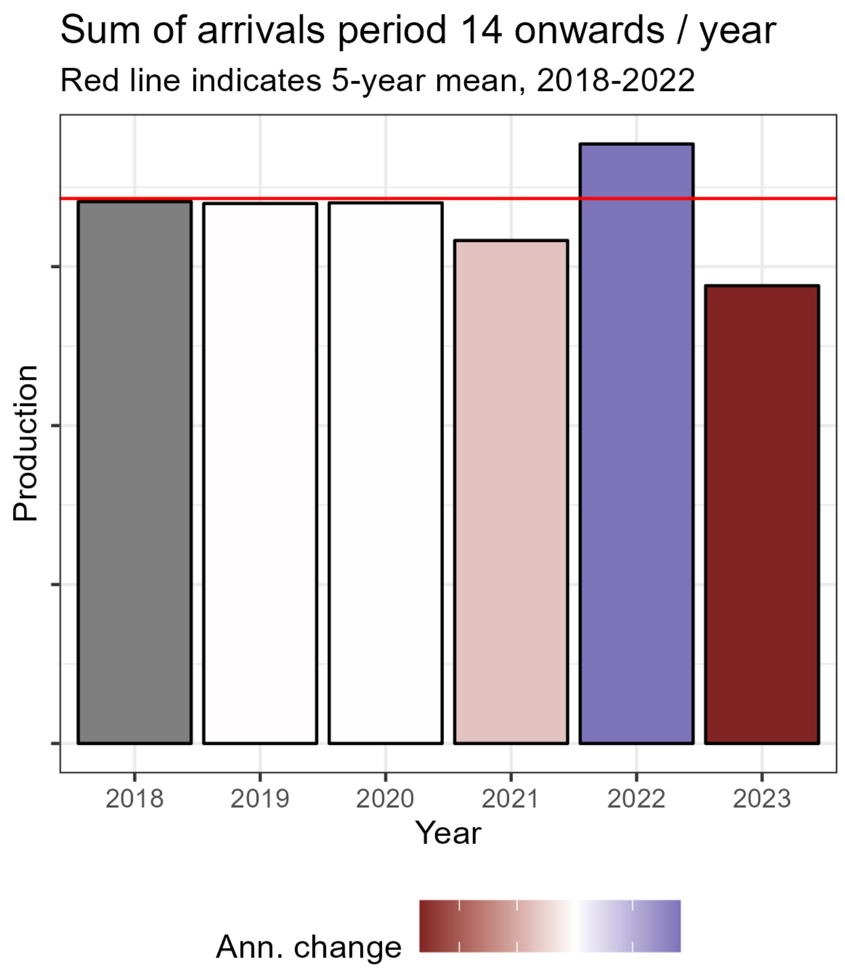
Objectives

- To what extent can climate explain this crash in production?
    - What about production variation more generally?
- Can we use climate data to predict production shocks in future?
- Reflect on how CocoaSoils can help!

What happened to cocoa production in the main season of 2023/24, as at Dec 2023?

- 2023/24 main season production was the lowest of the last 5 years
- And was 30-35% lower than 2022/23 (as at Dec 2023)
- But! 2023/24 was ~15% lower than the average main season production 2018-2023.
- 2022/23 was a very good season, and
- ...**the change from very good to very bad was extremely large!**

- What made 2023/24 a poor season? What made 2022/23 such a good season? → can climate explain this?
  - Observations for 2023/24: flowering was good, pod-set was poor, losses to black pod were high
  - Heavy rain in July/August, warmer than usual?



Methods: data sources

- Production data – based on Mondelez Trek Teams;
  - 25-farm sample for each of 11 regions across Cote d’Ivoire
  - Surveys conducted every 3 weeks
  - Data collected since 2012.
  - Ideally we wanted YIELD data, but we have PRODUCTION data (confounded with changes in area harvested):
    - focus on period **2018-2023**.
  - *Note: commercially sensitive.*
- Weather data
  - Daily, 10-day and/or monthly **observed rainfall/temperature** data, kindly supplied by CNRA.
  - Monthly relationships with NASA Power (satellite-derived) data determined for “bias adjustment”
  - Bias-adjusted daily **NASA Power data used for gap-filling and additional variables** (solar radiation, relative humidity)
  - NASA Power used directly when no observations were available

Methods: data analysis

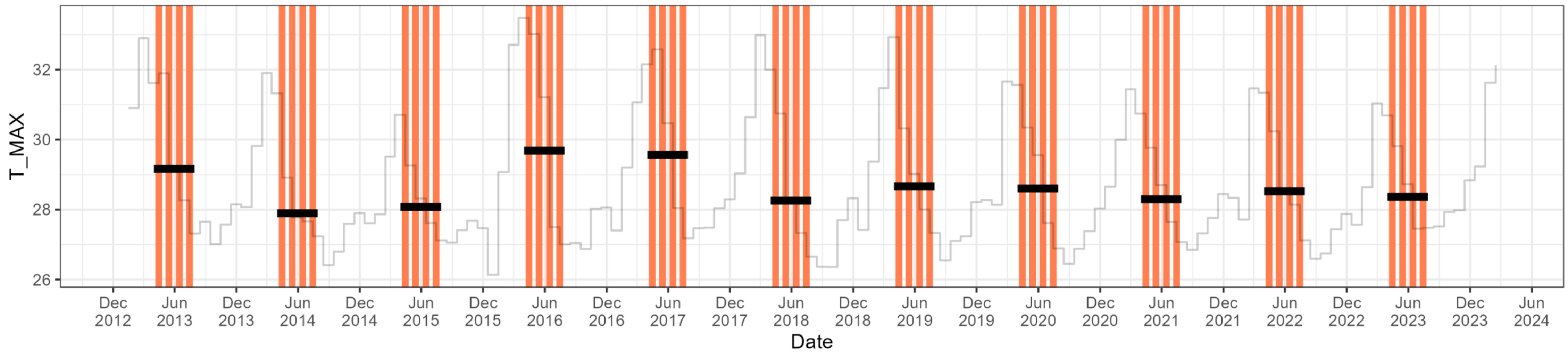
- Considered **phases** of the year:
  - Production: Main season to December = October to December = "**MainDec**"
  - Flowering phases:
    - MainFlowering = April-July
    - PeakMainFlowering = July
  - Pod filling phase:
    - BlackPodRisk = July-August
    - PeakMedPodMainSeas = August-September (black pod risk)
- **Weather data summaries** for these phases:
  - Sum of rainfall, Average temperature, avg. TMIN, TMAX, highest and lowest deciles of both, average relative humidity, sum solar radiation (sunlight)
- **Regions**
  - Cote d'Ivoire is big and spatially variable
  - **11 regions** available

- Statistical analysis
  - Per phase and region:
    - **Linear regression** of predictor variables against MainDec yield (across 6 seasons: 2017/18-2023/24)
    - Limited to 2 predictor variables for 2018-2024 to avoid overfitting
  - **Shortlisting** of promising models (predictor variable x phase combinations) – performance vs complexity
  - Final predictive model per region
  - Interpretation –what climate anomalies explained 2022/23 and 2023/24 production anomalies?

Concept of phases

Vertical lines show months part of the "main season flowering" phase (April-July)

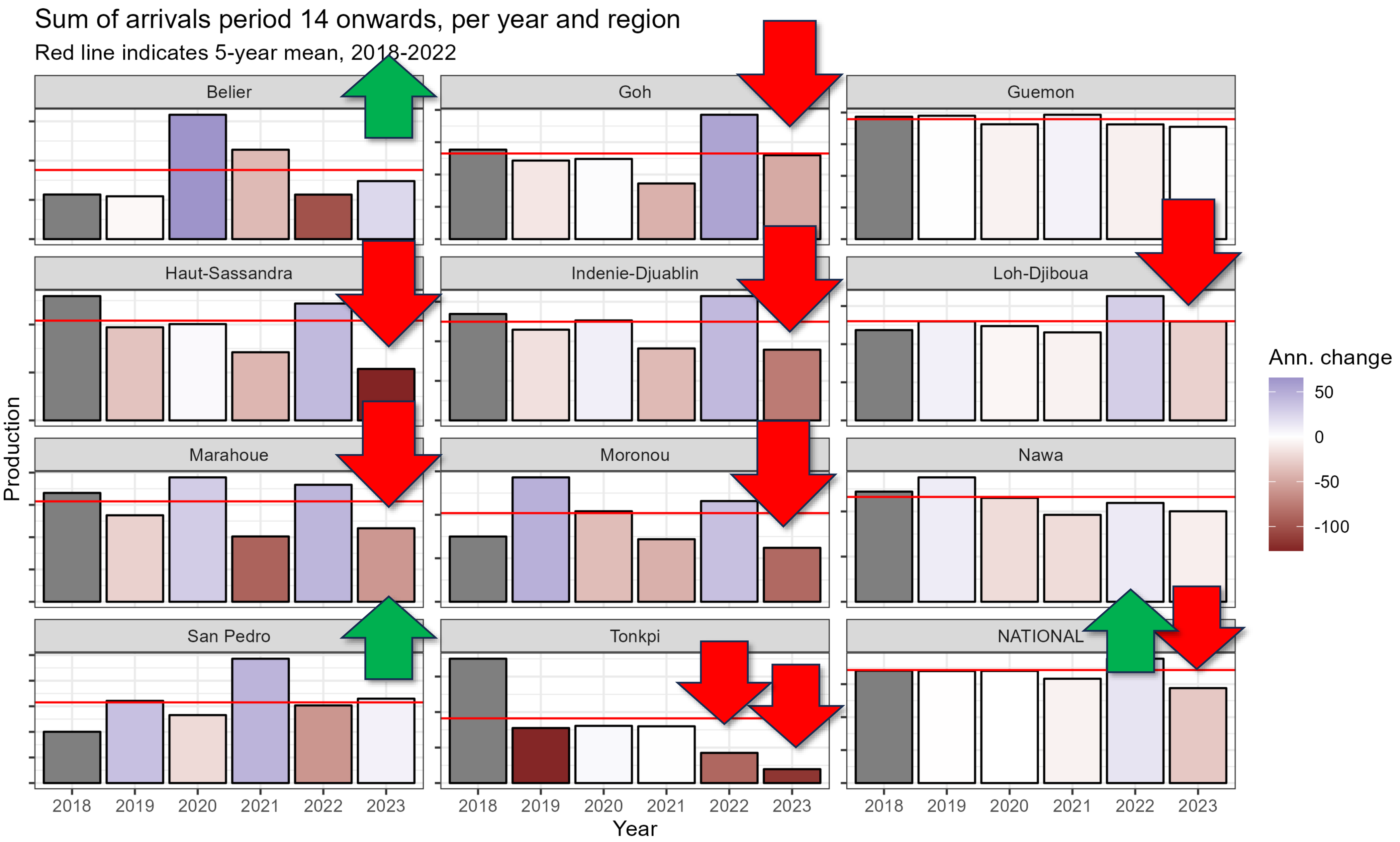
TMAX mean per phase, per year



Similar summaries calculated

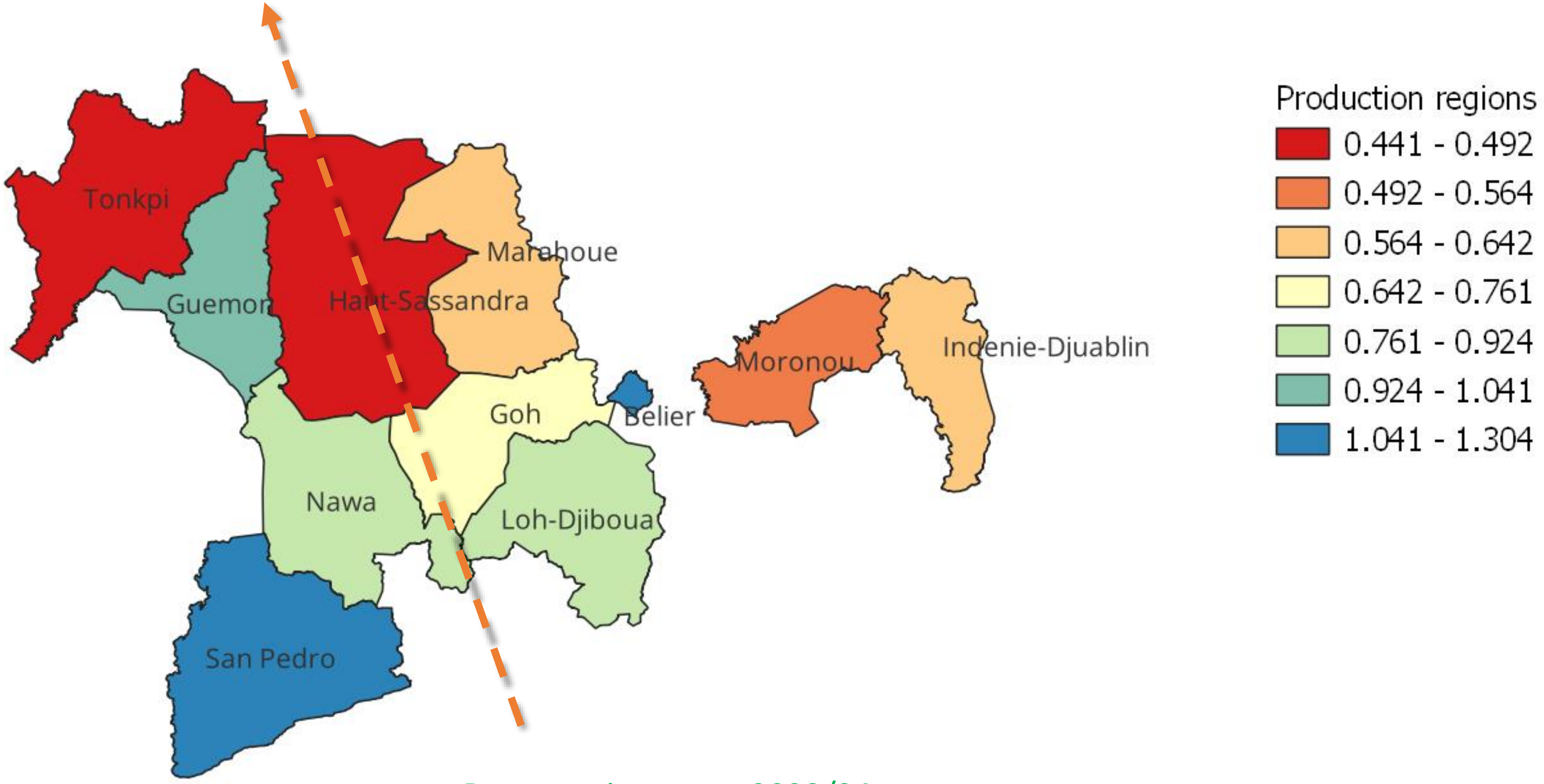
- per predictor variable (Rainfall, TMIN, simulated drought stress, etc) and
- per phase (mid, July-August, etc)

Results: regional



Regions

Poorer main season 2023/24



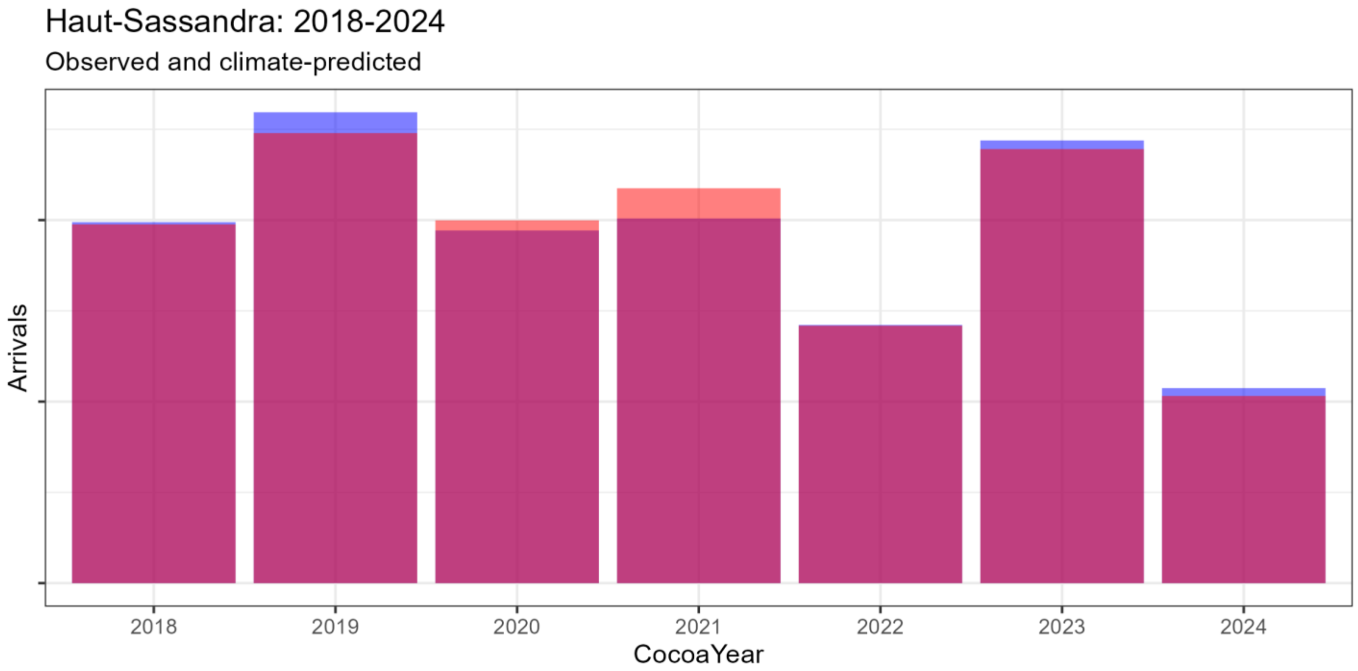
Better main season 2023/24

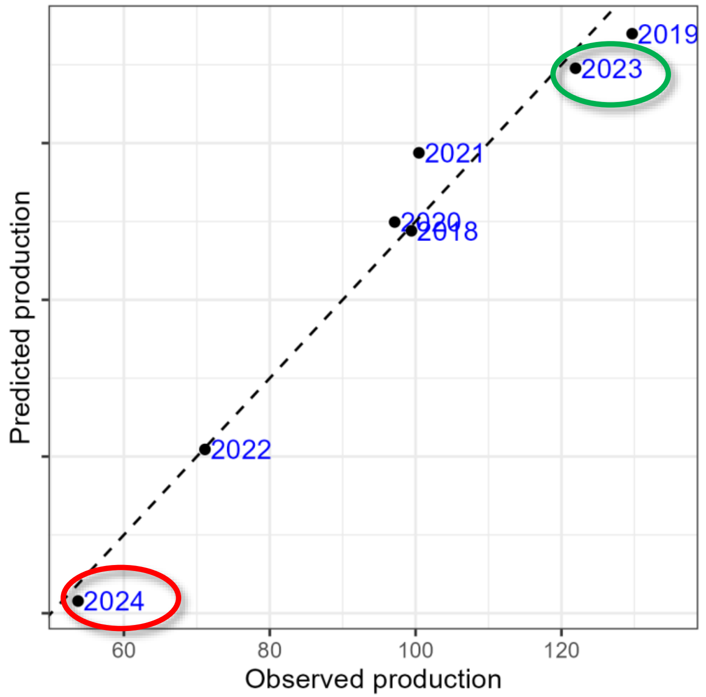
Results: Haut-Sassandra

Most promising model:
$Production \sim -12.1(RH\%) - 0.86(SRAD)$

during the **MainFlowering phase, April-July**

Fitted to data 2018-2024, R^2 = 0.97





Region	CocoaYear	RH.MainFlowering	SRAD.MainFlowering
Haut-Sassandra	2018	83.2	2162
Haut-Sassandra	2019	86.8	2082
Haut-Sassandra	2020	87.5	2100
Haut-Sassandra	2021	86.8	2100
Haut-Sassandra	2022	88.3	2123
Haut-Sassandra	2023	86.9	2086
Haut-Sassandra	2024	88.5	2142

Poor year (2024):
High RH%, high solar radiation during main flowering season.

Great year: low RH% and radiation during main flowering season

- Note: weather data for Haut-Sassandra are from NASA Power; range of values is probably underestimated.
- Can these small differences in RH% and SRAD make such a difference??

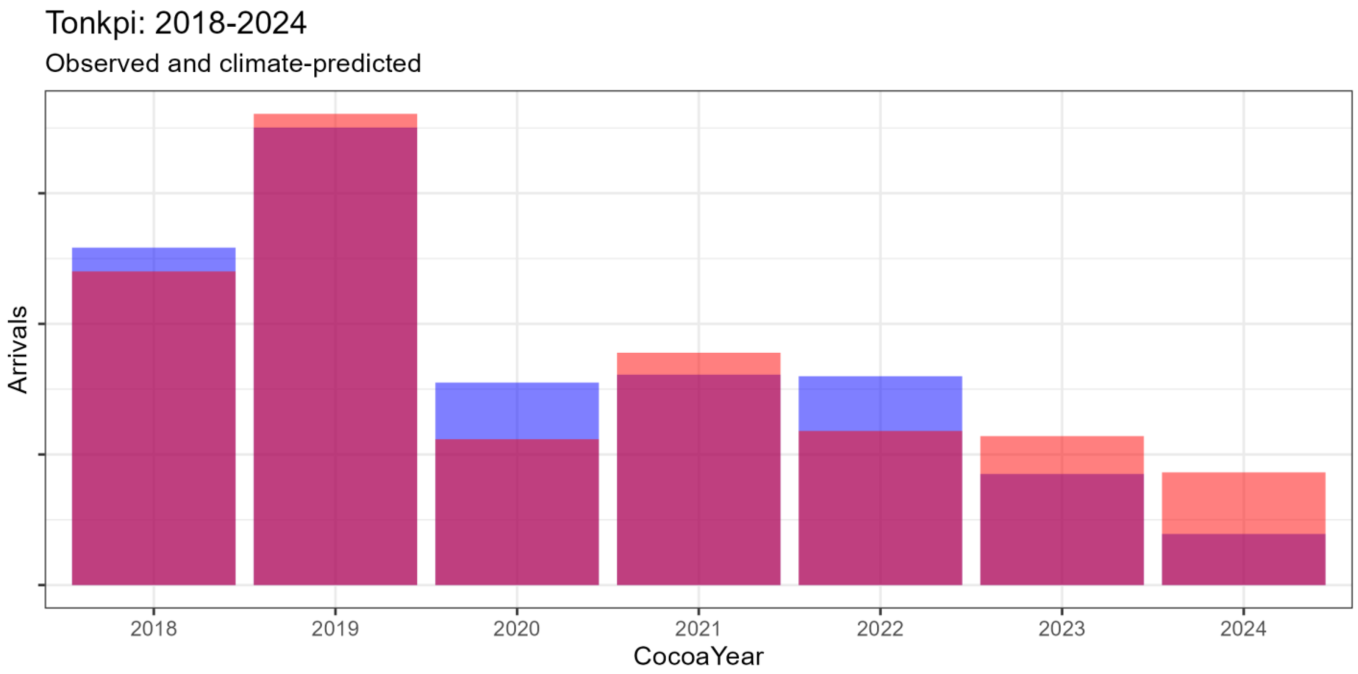
Results: Tonkpi

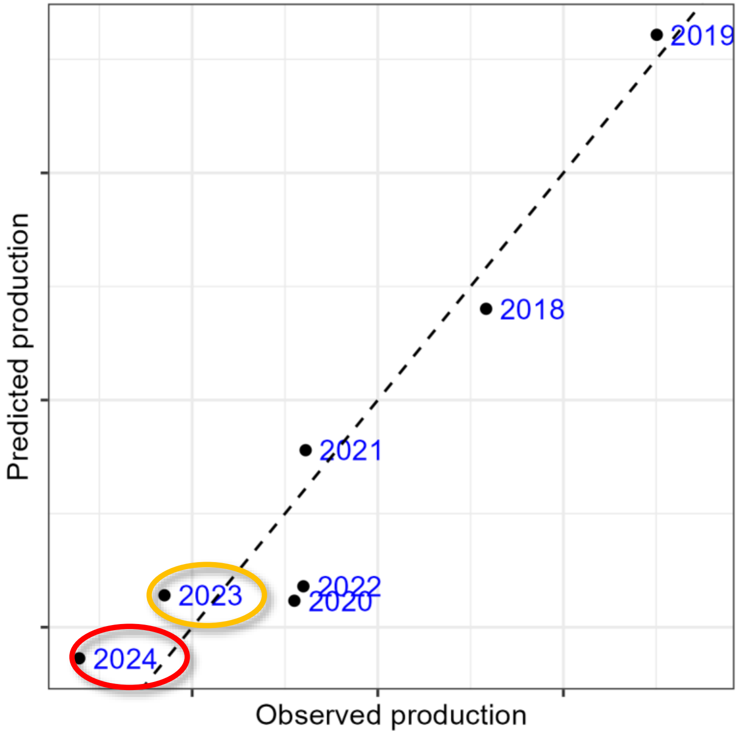
Most promising model:

$$Production \sim 0.66(SRAD) - 76.9(TMAX)$$

during the **PeakMainFlowering phase (July)**

Fitted to data 2018-2024, $R^2 = 0.89$





Region	CocoaYear	T_MAX.PeakMainFlowg	SRAD.PeakMainFlowg
Tonkpi	2018	27.2	489
Tonkpi	2019	26.7	465
Tonkpi	2020	27.3	468
Tonkpi	2021	26.9	437
Tonkpi	2022	27.1	440
Tonkpi	2023	27.1	444
Tonkpi	2024	27.5	478

Poor year (2024): High solar radiation, high TMAX during peak main flowering season (July).

Great year (2019): cool days (low TMAX) during peak main flowering season

- Note: SRAD from NASA Power; TMAX is observed/bias-adjusted obs.
- TMAX alone captures the differences between good and bad years
- Best model for detrended 2013-2024 included SRAD and TMAX with similar coefficients

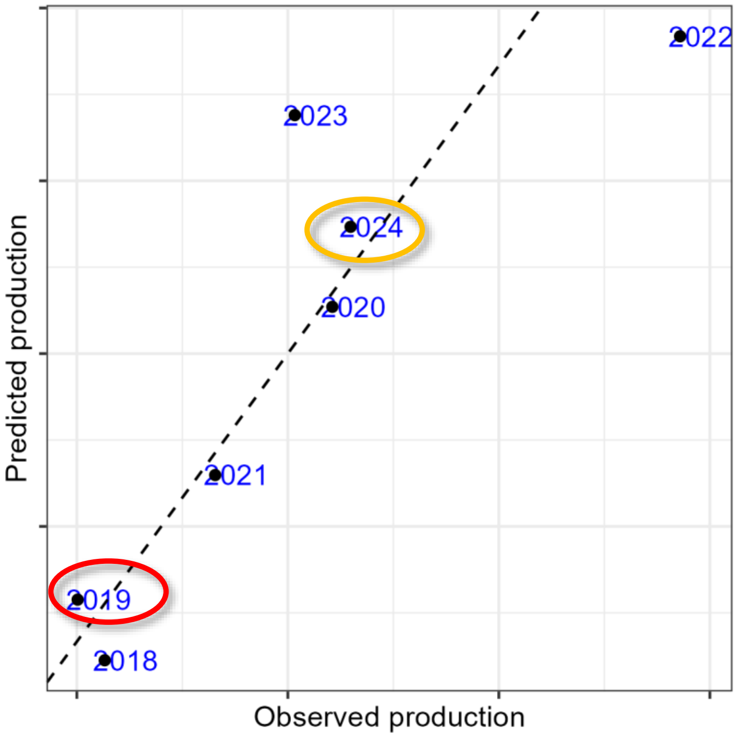
Results: San Pedro

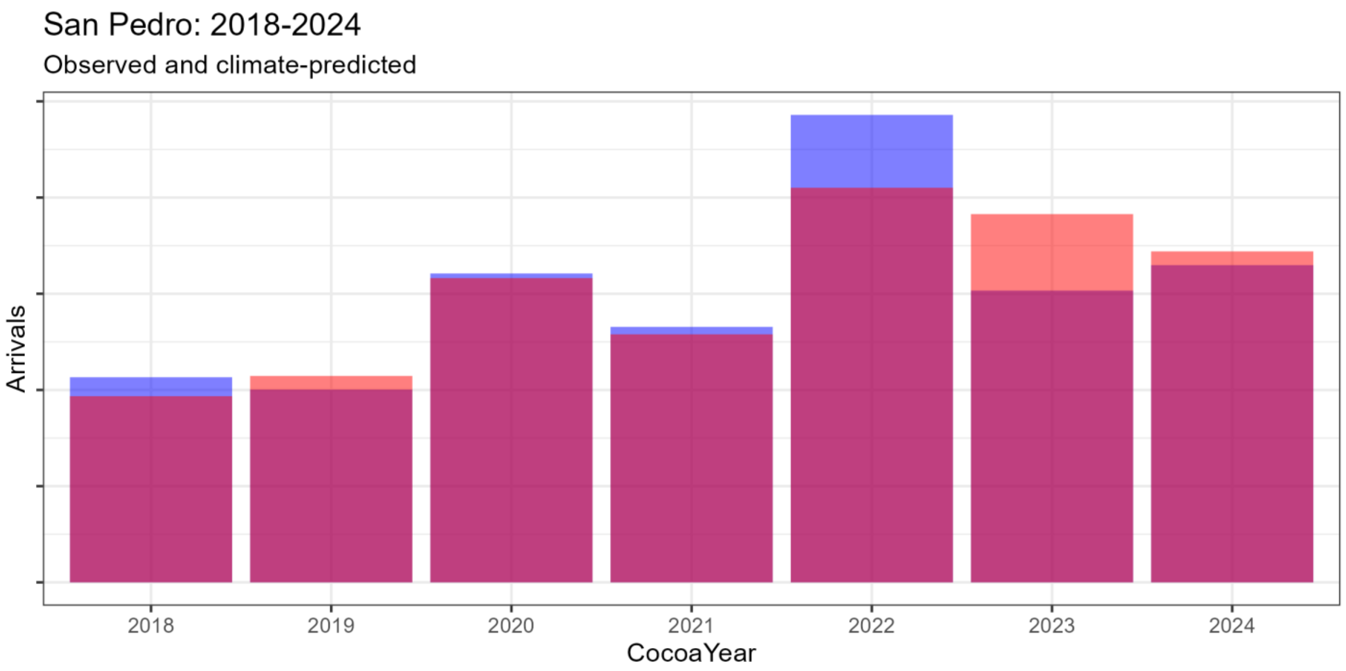
Most promising model:

$$Production \sim 1.13(RAIN) + 65.7(TRANGE)$$

during the **PeakMainFlowering phase (July)**

Fitted to data 2018-2024, $R^2 = 0.76$





Region	CocoaYear	TRANGE	RAIN
San Pedro	2018	6.8	102
San Pedro	2019	6.2	147
San Pedro	2020	6.6	170
San Pedro	2021	6.6	144
San Pedro	2022	6.6	209
San Pedro	2023	6.8	185
San Pedro	2024	6.1	208

Poor year (2019): low TRANGE (small difference between TMAX and TMIN) and low rainfall during peak main flowering season (July).

Great year (2022): high TRANGE and higher rainfall during peak main flowering season (July)

- Note: SRAD and TRANGE from NASA Power
- Not all variation is captured – influence of management changes?

Summary of models

Best model fits, 2018-2024													
Region	**PredPhase**	**RAIN**	**RH**	**SRAD**	**T_MAX**	**T_MIN**	**TAVE**	**TRANGE**	**Rsq**	**F**	**logLik**	**AICc**	**delta**
Guemon	MainFlowering			-0.24*				-30.69**	0.97	65.24	-17.27	62.54	3.01
Haut-Sassandra	MainFlowering		-12.06***	-0.86***					0.97	68.56	-19.89	67.78	0.00
Marahoue	MainFlowering			-0.35*				31.98*	0.81	8.33	-22.36	72.71	6.33
Nawa	MainFlowering			-0.64***		77.87**			0.95	39.71	-18.52	65.03	0.00
San Pedro	PeakMainFlowering	1.13*						65.69	0.76	6.43	-31.41	90.81	10.95
Tonkpi	PeakMainFlowering			0.66*	-76.90**				0.89	15.51	-23.05	74.10	4.37
Belier	PeakMedPodMainSeas			0.51^{s}		-36.01			0.61	3.10	-25.52	79.03	8.99
Goh	PeakMedPodMainSeas			-1.26*		31.28			0.77	6.56	-28.55	85.09	11.99
Indenie-Djuablin	PeakMedPodMainSeas			-0.55*			-18.08		0.91	20.83	-21.58	71.16	9.01
Loh-Djiboua	PeakMedPodMainSeas	0.14	23.32*						0.72	5.15	-26.64	81.28	9.02
Moronou	PeakMedPodMainSeas		32.78*					86.32^{s}	0.72	5.06	-22.37	72.75	9.23

`Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘s’ 0.1 ‘ ’ 1`

- Regions where “best” predictor variables are from the flowering phase (main or peak) → sink strength limitations (e.g. poor flowering, excessive Cherelle wilt)
- In other regions, source strength (or black pod infection?) may explain variation.
- Variation in rainfall was less important.
- Not all coefficients are significant

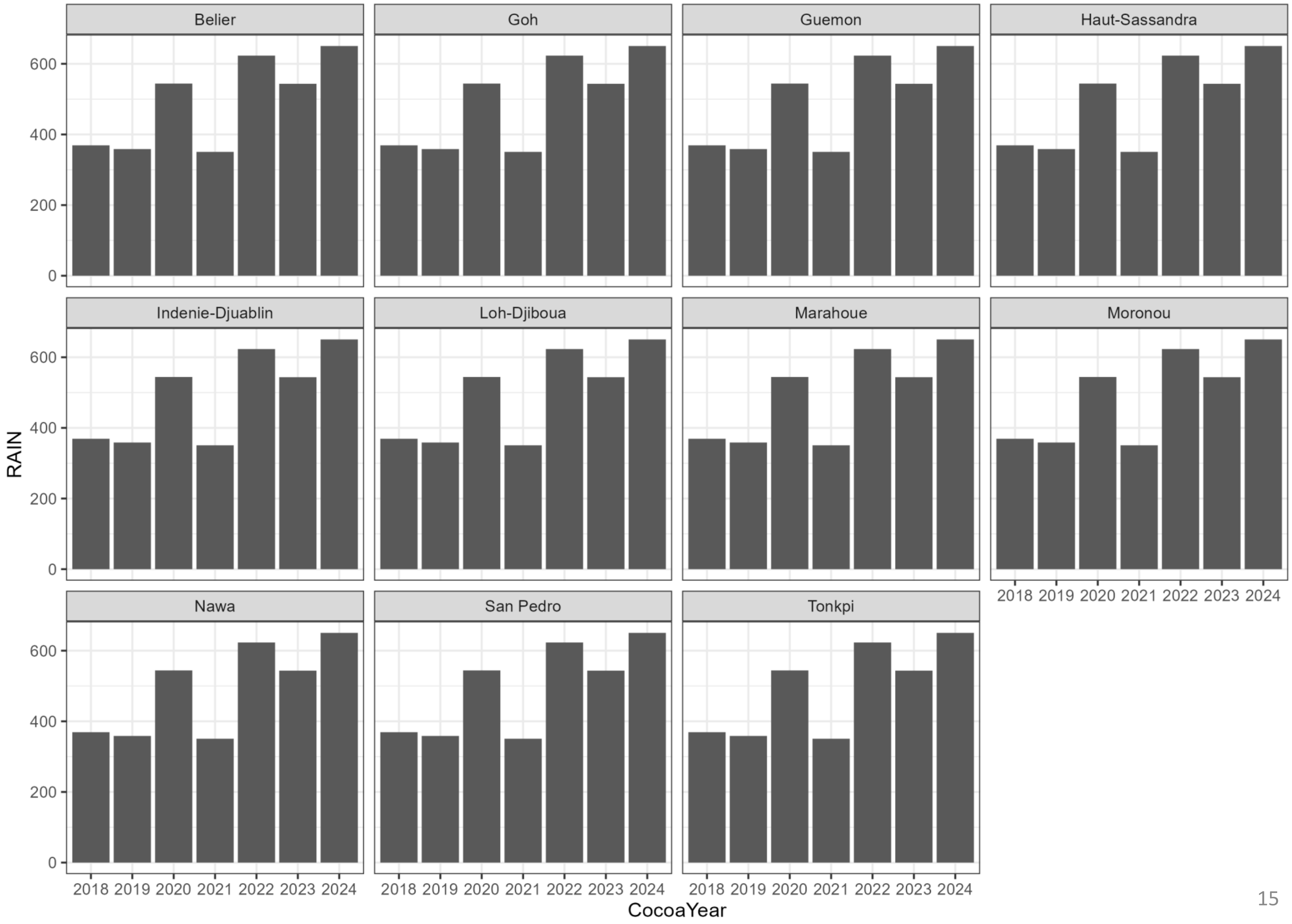
Pest and disease impacts

- Very high (above-normal) rainfall in all regions in July-August 2023
- Waterlogging + high RH% + high temperatures → black pod risk
- Marahoue, Nawa, Haut-Sassandra, Tonkpi and Indenie-Djuablin all had negative rainfall regression coefficients for JulyAug phase explaining variation in MainDec yields.
  - i.e. more rain is bad during this phase in these regions
- Haut-Sassandra: negative coefficient on T_MAX, Marahaoue: neg. coefficient on T_MIN
- Conversely
  - in Guemon, higher RH% and RAIN during JulyAugust phase correlated with higher MainDec yields
  - San Pedro, higher RAIN is favoured but higher T_MIN correlated with poorer yields.
- CSSV is suspected based on feedback from the field

JulyAugust rainfall per Season

NOTE:

- mix of observed and satellite data
- Satellite data are not verified

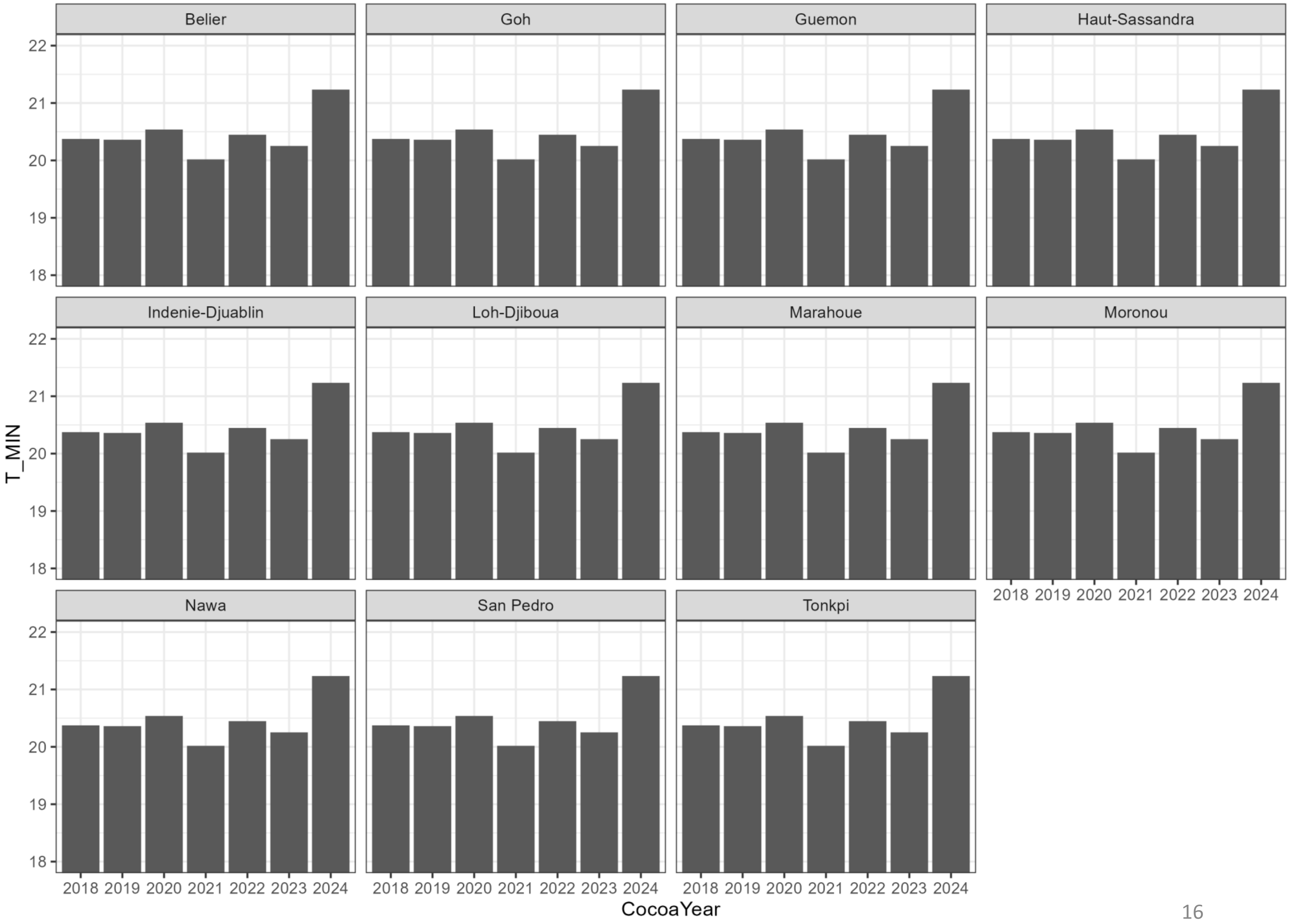


JulyAugust TMIN per Season

UNUSUALLY WARM (+1 C) in all regions in JulyAug 2023.

NOTE:

- mix of observed and satellite data
- Satellite data are not verified



Discussion

- Robustness of statistical analyses (some ideas for improvement)
- Prediction of future shocks – perhaps!
  - Quality of analyses higher with obs weather data; easier with the NASA Power
  - Weather data are valuable
- Can we explain – physiologically – the effects we observe? No!
  - But these insights can perhaps direct research
  - Real weather data essential here!
- Role of management changes? (Direct or indirect)
  - Insights are for average farms. Are there management interventions that can compensate for, or enhance, climatic effects?
- Value of CocoaSoils satellite data as a network of monitor sites with different management intensity levels
  - MDLZ dataset is confidential – but CocoaSoils data are open to participants
  - Weather stations – accurate data required for physiological insights

Next steps

- Cross-validation to improve reliability of models
- Allow climate variables from multiple phases in the same model (preferably on the full detrended dataset, 2013-2024)
- Yield dataset?
- Combine regions with similar patterns – can one model serve many regions?
- Can these results inform physiological understanding? (Combine with observations of black pod, CSSV, etc).
  - Accurate (observed) weather data required!

Conclusions

- We found it possible to model production variability and the 2023/24 “crash” using climate data, at least in some regions
- Is this the whole story?
- Preliminary insights – more robust modelling to validate responses required! (Risk of overfitting!)
- Linking to physiological causes
- Role of management
- CocoaSoils satellite trials as monitor farms
- Value of observed weather data