Responding to Climate Variability and Change: A Rapid Prototype For Assessing Impacts of Uncertainty in Climate Observations and Model Projections on Decision Support

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Stakeholders:
Regional Committee on Hydraulic Resources
Regional Monitoring and Visualization System for Mesoamerica

Outline

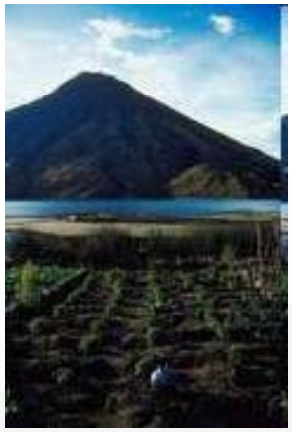
- ❖Sources Of Uncertainty in Climate Science and Applications
- ❖Crop Yield Prediction Process
- ❖ Analysis Of Results
- ❖ Uncertainty Characterization and Communication

Committee On Earth Observation Satellites (CEOS) Purpose & Scope

Societal Benefit

Decision Topic

What is the impact of climate change (temperature and precipitation) and its uncertainty on the change to agriculture yield in Central America and how will it impact water resource management decisions in that region?



Information Products and Services

- Temperature Forecasts
- Precipitation Forecasts
- Decision Support Tools

IPCC Scenarios

SERVIR and DSSAT – Central America

Uncertainty Analysis

Examine the uncertainty at every level (measurements to forecasts) and determine the impact on a specific decision.

Science Knowledge and Models

- Regional Climate Models (RCM)
- Global Circulation Models (GCM)

WRF – Central America

- NCAR Community Climate System Model (CCSM)

Precipitation
Temperature

Measurements

Earth observation satellites

Instruments and Missions

Booz | Allen | Hamilton

Sources of Uncertainty Analyzed

- **Climate Uncertainty**
  - **Rainfall uncertainty regarding the effect of rainfall on maize yield**
  - **Temperature uncertainty regarding the effect of temperature on maize yield**
- **Emission Uncertainty**
  - **Two emission scenarios affect the maize yield, rainfall, and temperature predictions for all of the models**
- **Model Uncertainty**
  - **Global Circulation Model (GCM) Uncertainties**
    - **Uncertainty exists from model to model in that each model makes distinct predictions about maize yield, rainfall, and temperature**

Goals for Communicating and Displaying Uncertainties for Decision Support

- Develop a repeatable and traceable framework for characterizing uncertainty in climate modeling
- Isolate the few important factors impacting decision support from the trivial many
- Focus on incorporating all available information and sources rather than subjectively biased selections
- Incorporate insightful graphical communication that enables exploratory analysis of critical factors
- Provide answers to decision-makers that clearly communicate uncertainty and risk

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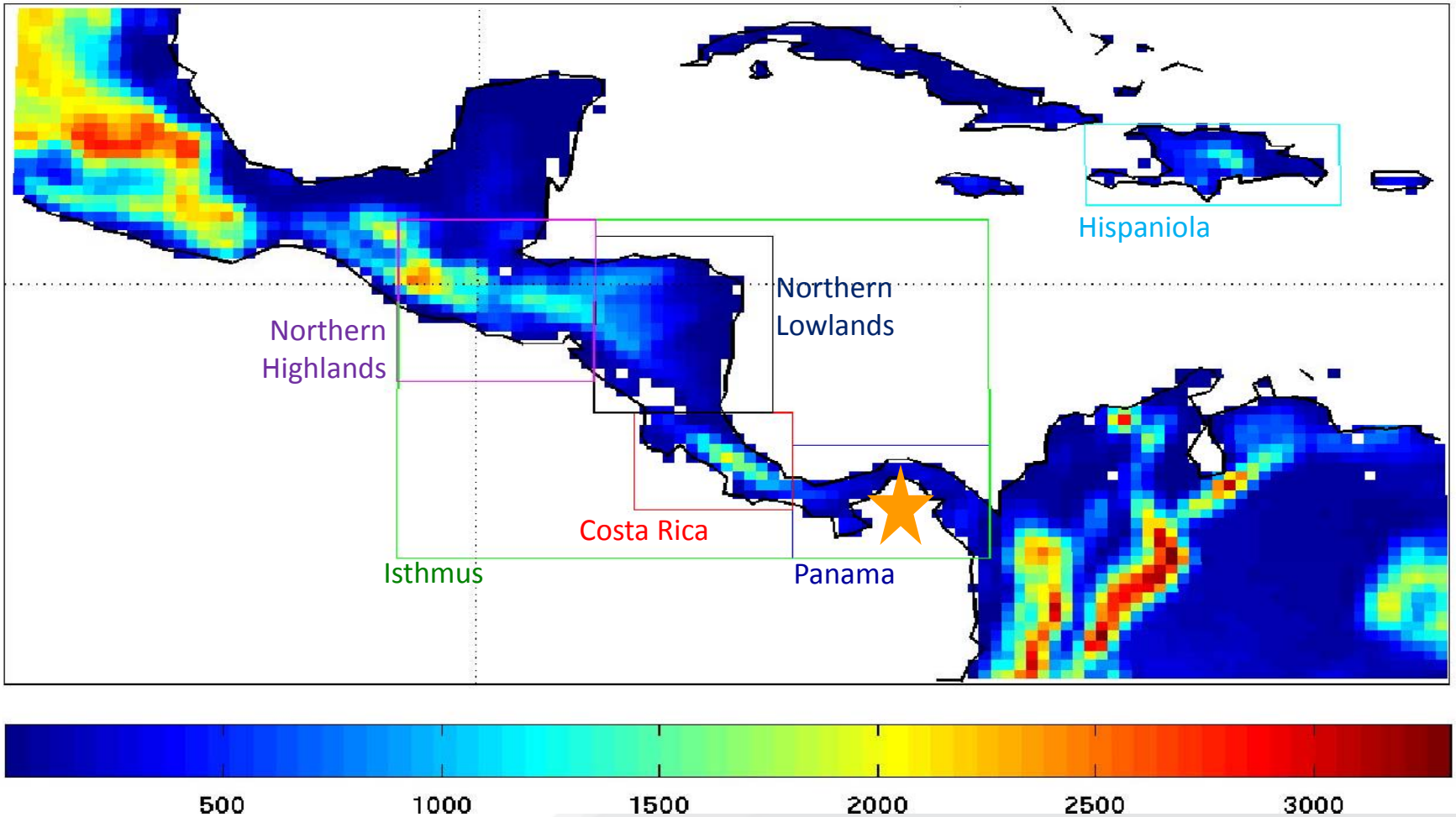
Focus Region For The Pilot Study

Domain Elevation and Sub-regions



Crop Yield Prediction Process - Overview

- The crop yield prediction process requires a synthesis of models and information:
  - Tocumen, Panama (located near Panama City), was selected as a trial location
  - This site was selected because of its longer history of daily meteorological observations
  - We generated crop yield data for maize based upon the characteristics of local fields, their agricultural practices, and observed meteorological conditions
  - Scenarios of climate change during the planting season were generated for the region
  - Yield simulations driven by historic and future climate scenarios are compared to determine the range of likely impacts of climate change.

Crop Yield Prediction Process – Crop Model

- Maize yield was simulated using the Crop Estimation through Resource and Environment Synthesis (CERES-Maize) biophysical crop model, which is an element of the Decision Support System for Agrotechnology Transfer (DSSAT) family of models

- CERES-Maize requires the following information:
  - Crop cultivar: genetic information about the crop to be grown
  - Field characteristics: soil type, initial moisture, field drainage, etc.
  - Agricultural management: planting dates and geometry, irrigation/fertilizer applications, etc.
  - Local meteorology: daily sunshine, min/max temperatures, and rainfall

Crop Yield Prediction Process – Future Climate

- **Climate change information was taken by comparing future (2020-2049) and baseline (1970-1999) climates from five climate models contributed to the Intergovernmental Panel on Climate Change (IPCC) 4th Assessment Report.**
  - **The A2 and B1 scenarios were examined to gauge societal uncertainties**
    - **For definitions of A2 and B1 see *IPCC Special Report Emissions Scenarios***
  - **Monthly temperature changes**
  - **Monthly rainfall percentage changes**
  - **Historic daily meteorology and carbon dioxide concentrations modified according to climate changes to produce future scenarios**

GCM Name	Institution	Atmospheric Resolution (lat, lon, °)	Equilibrium Climate Sensitivity (°C) for doubling of CO_2
gfdl_cm2_1	**Geophysical Fluid Dynamics Laboratory, USA**	**2x2.5**	**3.4**
giss_model_e_r	**NASA Goddard Institute for Space Studies, USA**	**4x5**	**2.7**
mpi_echam5	**Max Planck Institute for Meteorology, Germany**	**1.878x1.88**	**3.4**
ncar_ccsm3_0	**University Corporation for Atmospheric Research, USA**	**1.4x1.4**	**2.7**
ukmo_hadcm3	**Hadley Centre for Climate Prediction, Met Office, UK**	**2.5x3.75**	**3.3**

Rainfall & Temperature Projections Are Aggregated To Seasonal Periods Over The Prediction Range (2020-2049)

- **Temperature is measured in degrees Celsius**
  - **Chart represents the change in temperature from the baseline period**
- **Rainfall is measured in millimeters**
  - **Chart represents the percentage change in rainfall from the baseline period**

Temp Change	GFDL2.1_A2	GISS_Er_A2	ECHAM5_A2	CCSM_A2	UKMO_A2	GFDL2.1_B1	GISS_Er_B1	ECHAM5_B1	CCSM_B1	UKMO_B1
May	1.91	1.79	1.12	1.21	1.56	1.27	1.43	1.23	0.83	1.73
June	1.36	1.45	0.96	1.25	1.19	1.07	1.26	1.12	0.94	1.4
July	1.24	1.18	0.88	1.22	1.2	1.1	1.1	0.8	0.98	1.07
August	1.29	1.28	0.57	1.27	0.85	1.22	1.18	0.54	1.06	0.65
September	1.18	1.34	0.53	1.3	1.02	1.06	1.08	0.57	1.02	0.95

Rainfall Change	GFDL2.1_A2	GISS_Er_A2	ECHAM5_A2	CCSM_A2	UKMO_A2	GFDL2.1_B1	GISS_Er_B1	ECHAM5_B1	CCSM_B1	UKMO_B1
May	-4.6	-1.2	0.2	3.2	-5.5	18.6	-0.8	-8	-5.8	-13.5
June	-4.3	-5.5	1	0.8	18.7	-17.3	-5.1	0.2	2.1	7.7
July	-13.5	2.9	7.3	-7	0.6	-14.5	2	4.6	-4.1	2.4
August	-10.1	3	6.4	-4.9	7.5	4.6	-1.7	4.1	-1.7	1.2
September	-10.4	-2.6	0.1	-0.4	13.8	-2	-1	-7.2	6.3	3.3

Five GCMs Project Maize Yield Through IPCC Emission Scenarios A2 And B1

baseline yr	baseline	GCM yr	GFDL2.1_A2	GISS_Er_A2	ECHAM5_A2	CCSM_A2	UKMO_A2	GFDL2.1_B1	GISS_Er_B1	ECHAM5_B1	CCSM_B1	UKMO_B1
1970	4264	2020	3192	3397	3758	2926	3556	3122	3331	3664	3433	3589
1971	3026	2021	3418	3537	4321	3848	3910	3401	3621	4088	3810	3627
1972	5296	2022	5310	5537	5768	4980	5279	4932	5109	5410	5224	5588
1973	3922	2023	3273	3436	3774	3397	3547	3261	3378	3603	3553	3477
1974	3205	2024	3778	3714	4151	3639	3772	3803	3684	3994	3595	3868
1975	3813	2025	4267	4437	4784	4284	4572	4165	4369	4223	4146	4490
1976	2873	2026	3506	3747	3214	4014	4120	3846	3987	3044	3113	3805
1977	3086	2027	3624	3714	3396	3028	3785	3126	3672	3436	3174	3816
1978	4781	2028	4689	4863	5127	4550	4772	4569	4618	5223	4963	5025
1979	4150	2029	3813	3998	4504	3969	4306	3827	3880	4439	3864	4357
1980	1785	2030	2911	2982	2509	2198	2408	2306	2316	2249	2540	3106
1981	4213	2031	4142	4099	4341	3781	4409	3706	3933	4186	3782	4423
1982	3757	2032	3539	4031	4528	4069	4095	3648	3994	4238	4100	4104
1983	2635	2033	3170	3371	3762	3114	3364	3224	3366	3616	3062	3478
1984	3615	2034	3929	4092	3953	3514	4185	3468	4077	3755	3637	4054
1985	2490	2035	3119	3439	3410	3105	3314	2972	3147	3113	2975	3186
1986	1746	2036	3301	3087	3347	3322	3255	3029	3041	3316	2957	3149
1987	4012	2037	3922	4005	3704	3807	4521	3751	3738	3820	3801	4106

- **Yield is measured in kilograms per 10,000 square meters**

GCM

Baseline Observation

Time

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- Overview of CEOS and the Project
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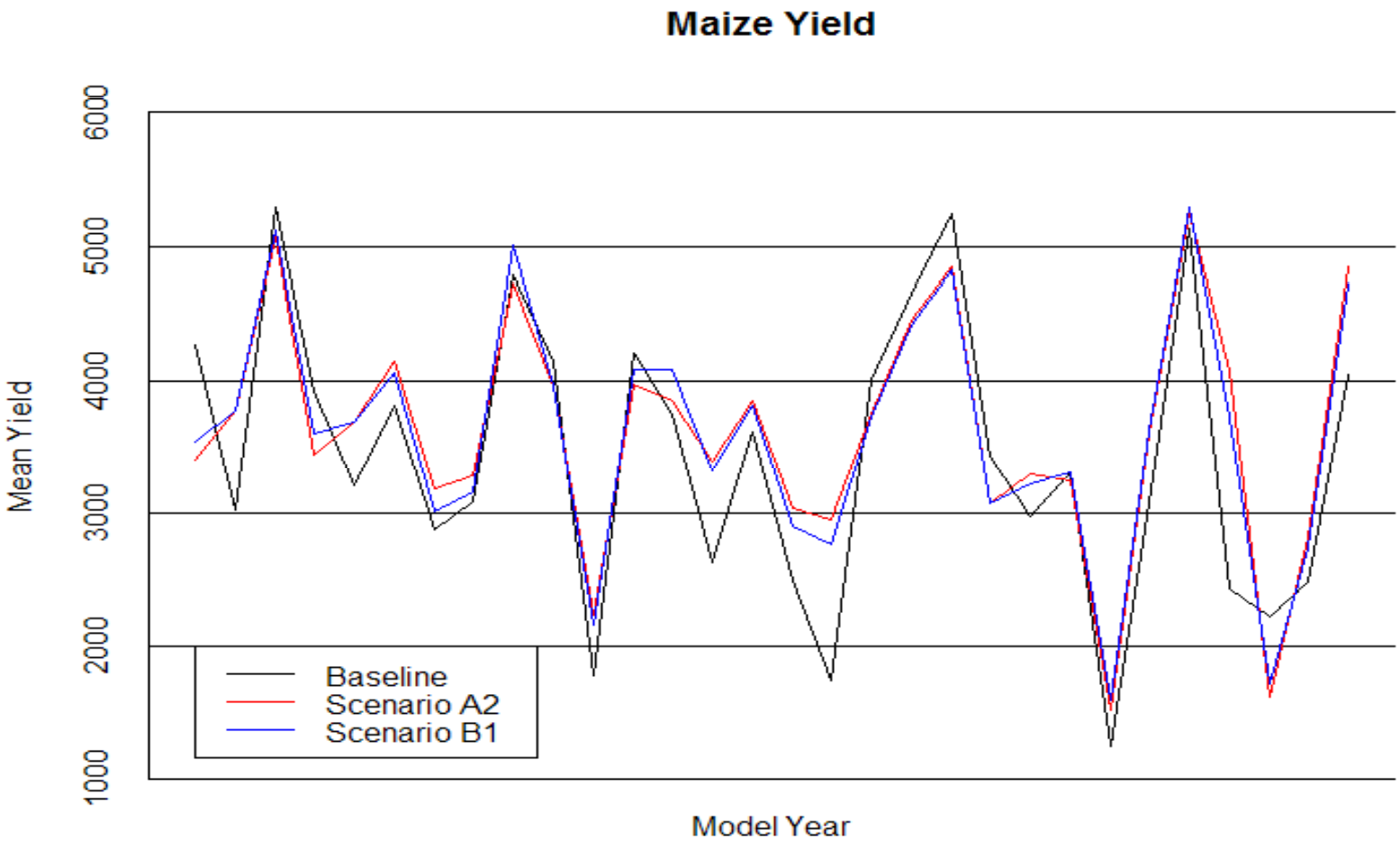
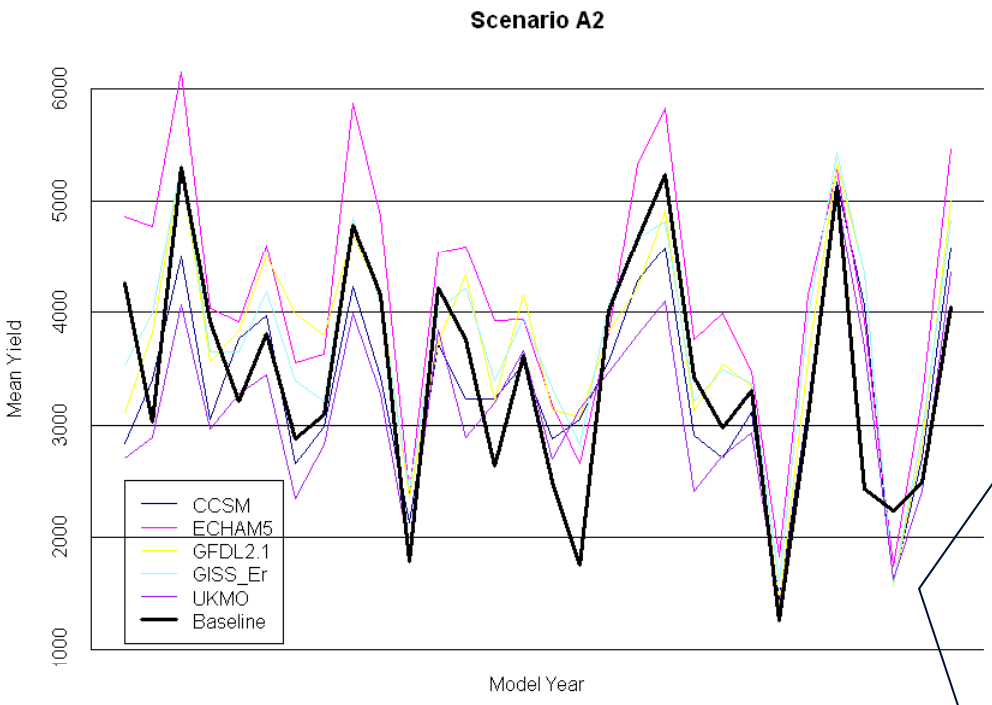
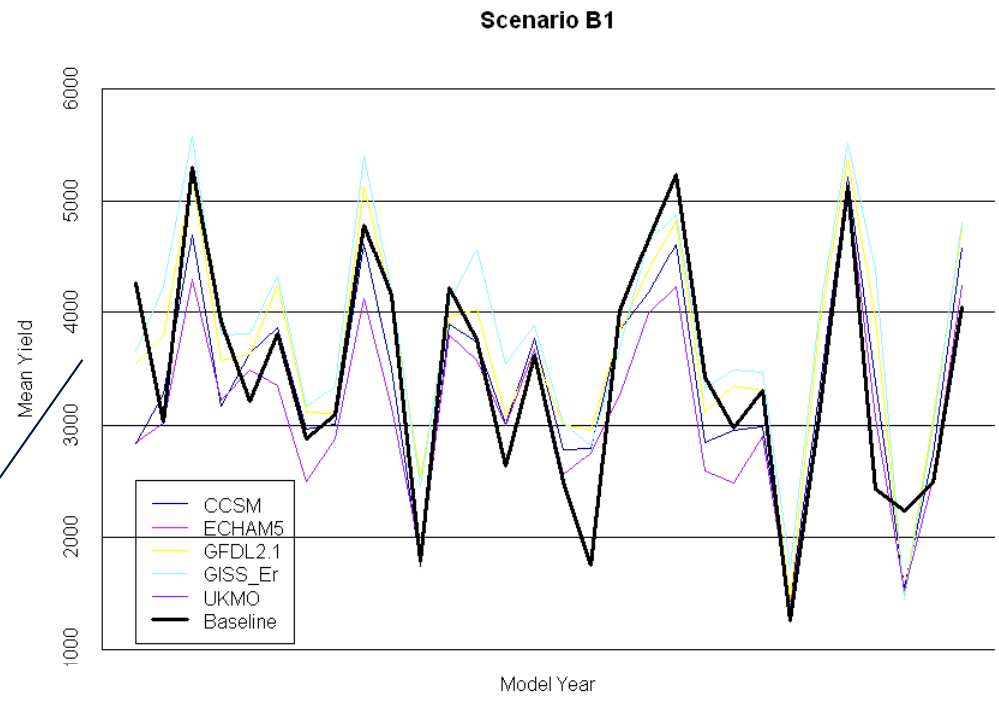
Baseline Maize Yield & GCM-Projected Maize Yield (2020-2049) By Scenario Across GCMs



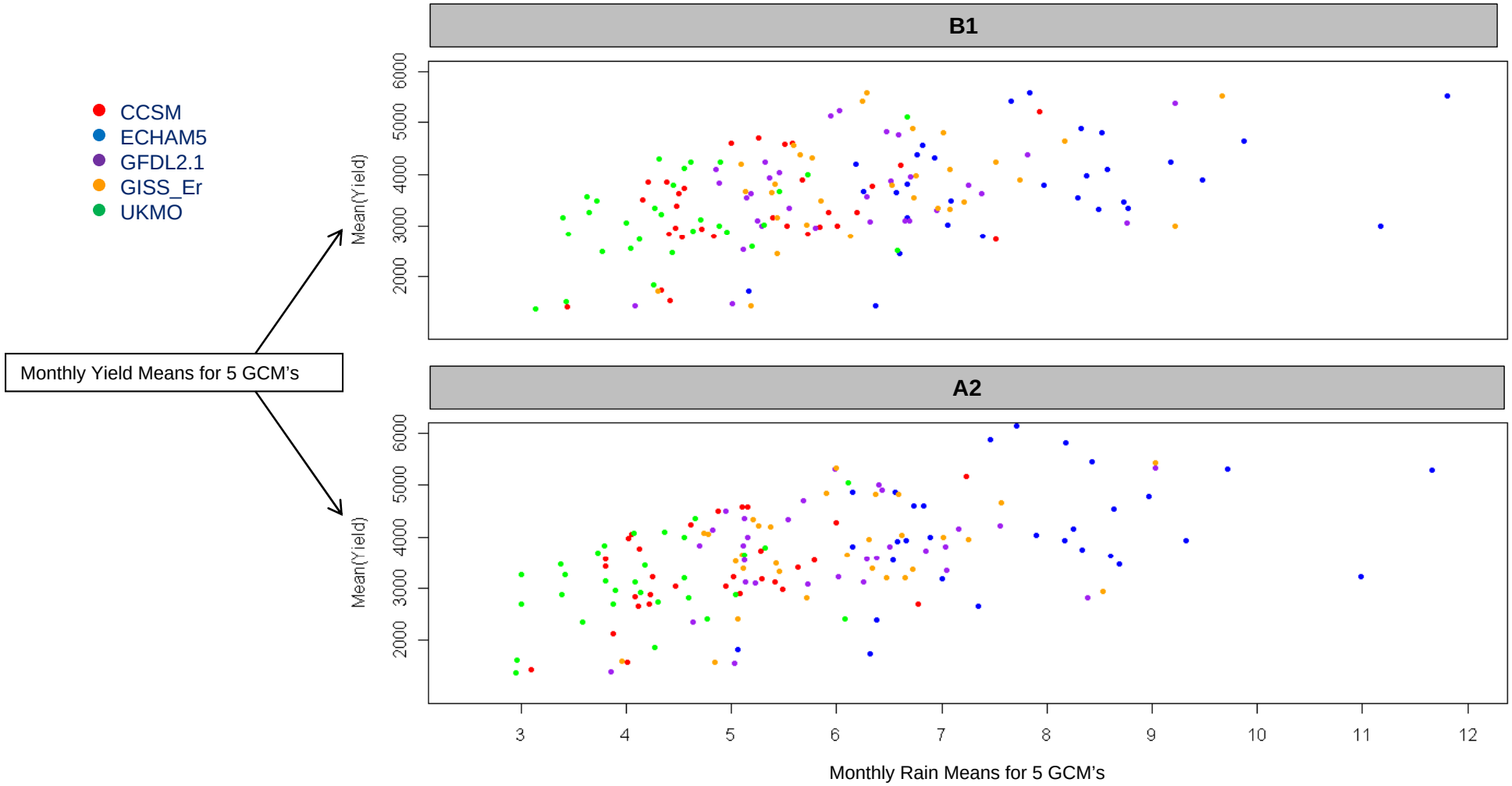
GCM-Projected (2020-2049) Maize Yield By Model & Scenario



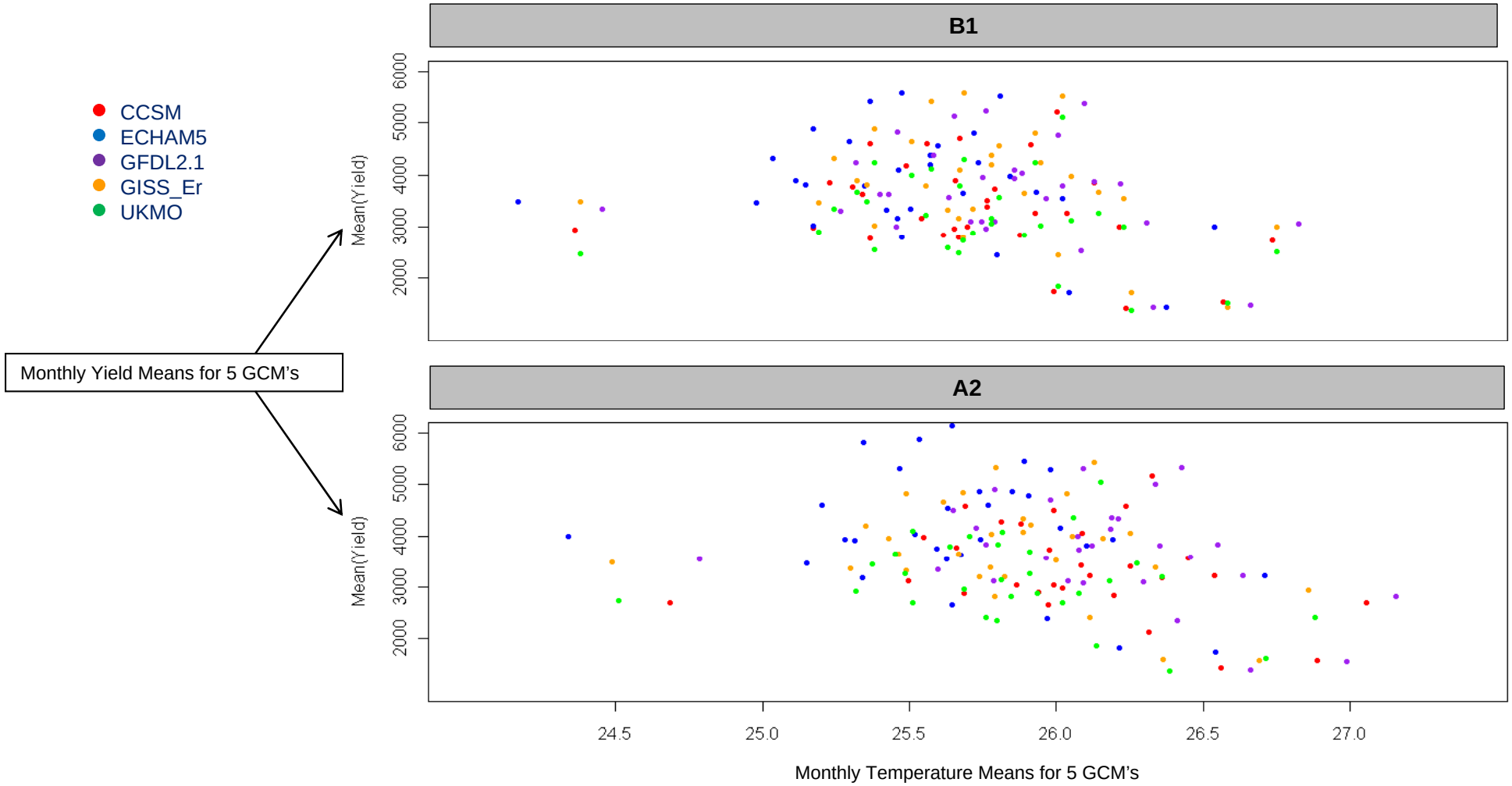


Average annual yield for GCM

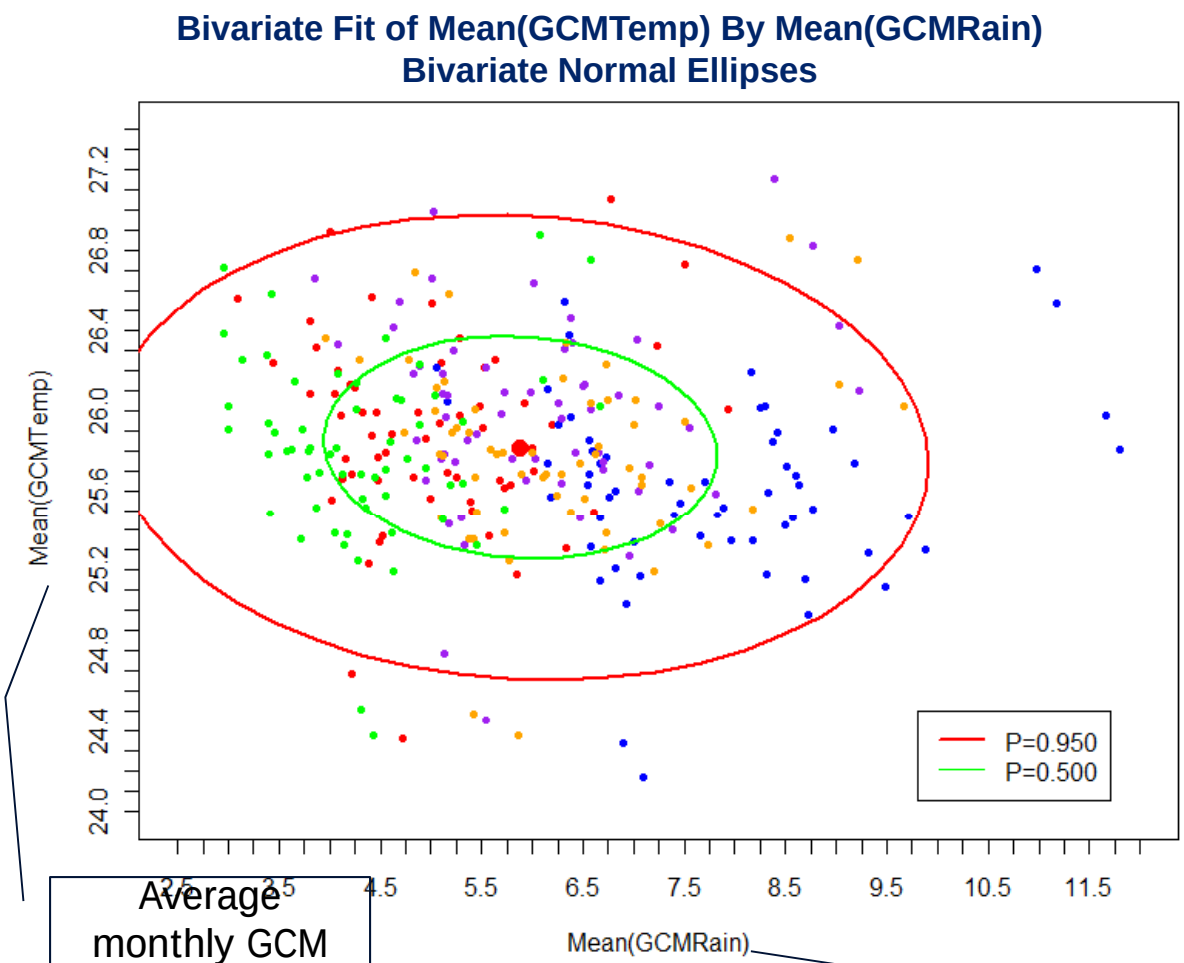
Rainfall & GCM-Projected (2020-2049) Maize Yield By Scenario



Temp & GCM-Projected (2020-2049) Maize Yield By Scenario



GCM Projections In Tocumen (2020-2049) For Temperature & Rainfall Display A Lack Of Correlation



Average monthly GCM temperature

Average monthly GCM rainfall

- Temperature and rainfall are not significantly correlated (Pearson test)
- 95% of the time
  - Temperature is between 24.6 and 26.6 Celsius
  - Rainfall is between 2.5 and 9.75 mm
- 50% of the time
  - Temperature is between 25.3 and 26.4 Celsius
  - Rainfall is between 4 and 7.75 mm

- CCSM
- ECHAM5
- GFDL2.1
- GISS_Er
- UKMO

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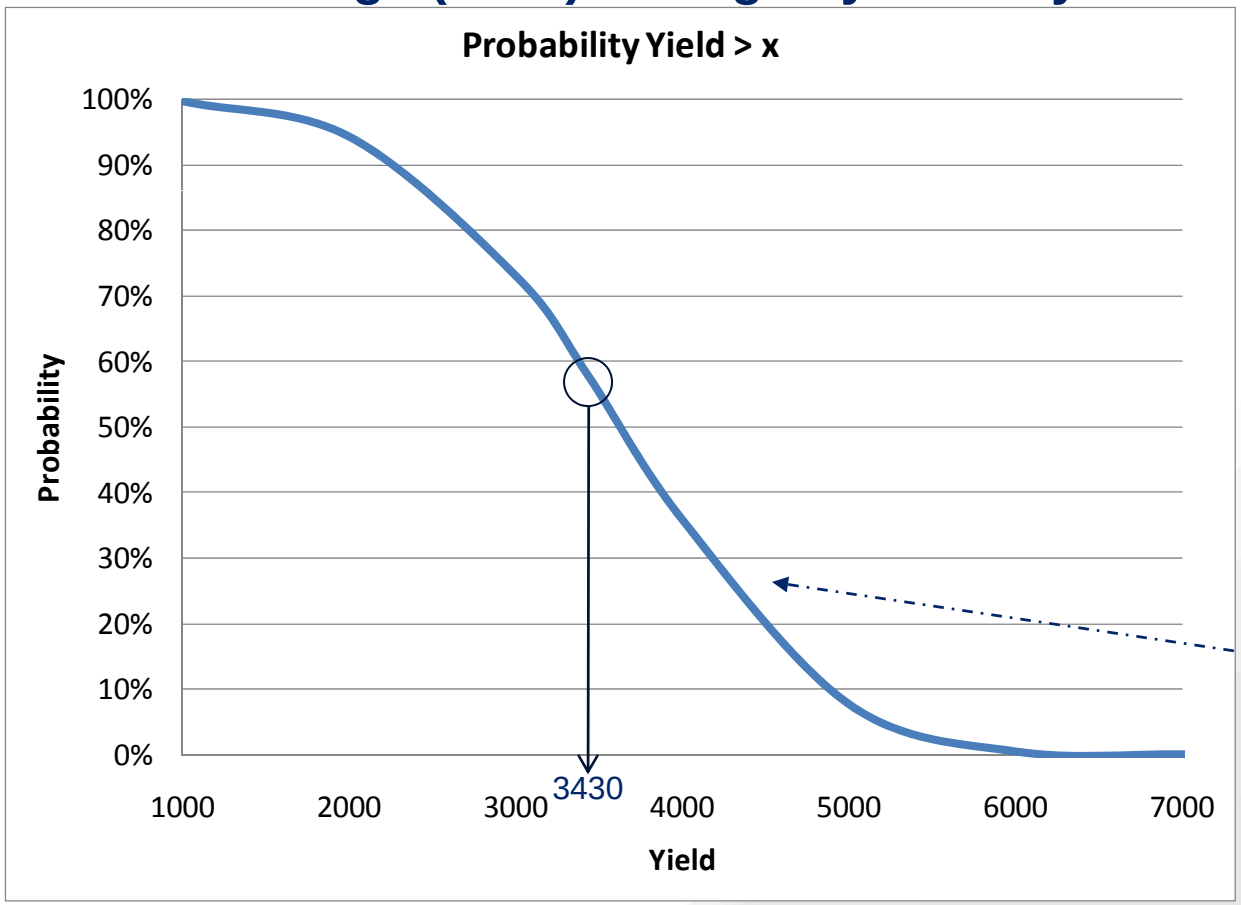
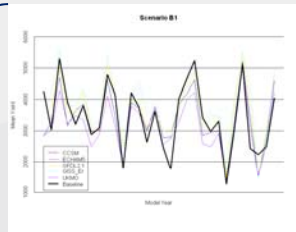
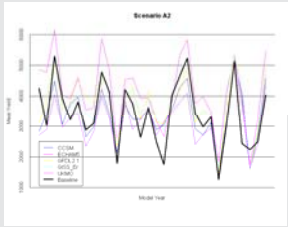
Distribution Analysis Deals With Uncertainty Across Years (2020-2049), GCMs, & Scenarios

❖ **The probability that Maize Yield will be above or below the baseline average (3430) during any future year**



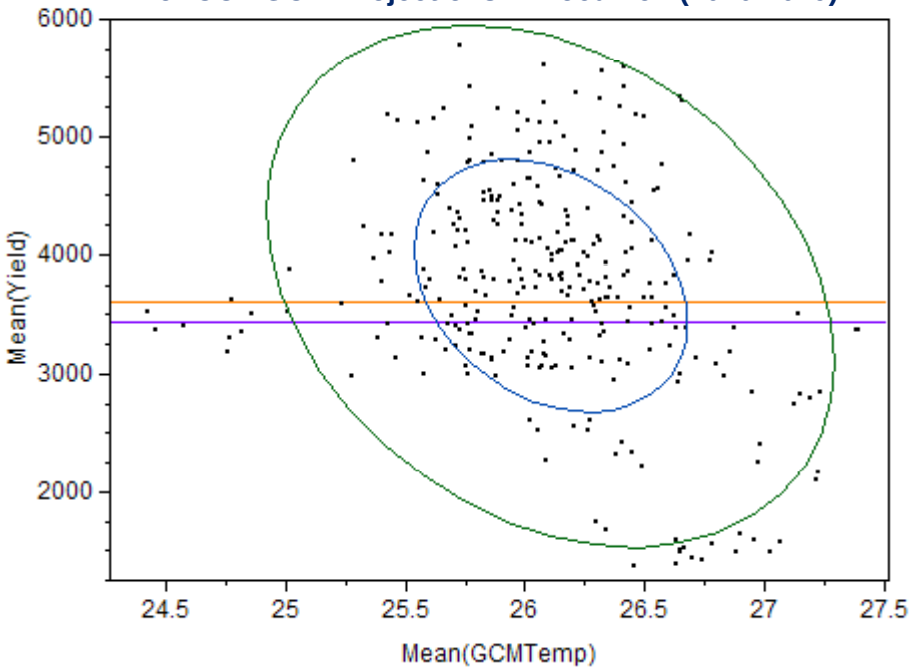
	Prob
Below Baseline (3430)	42%
Around Baseline (+/-10%)	26%
Above Baseline (3430)	58%



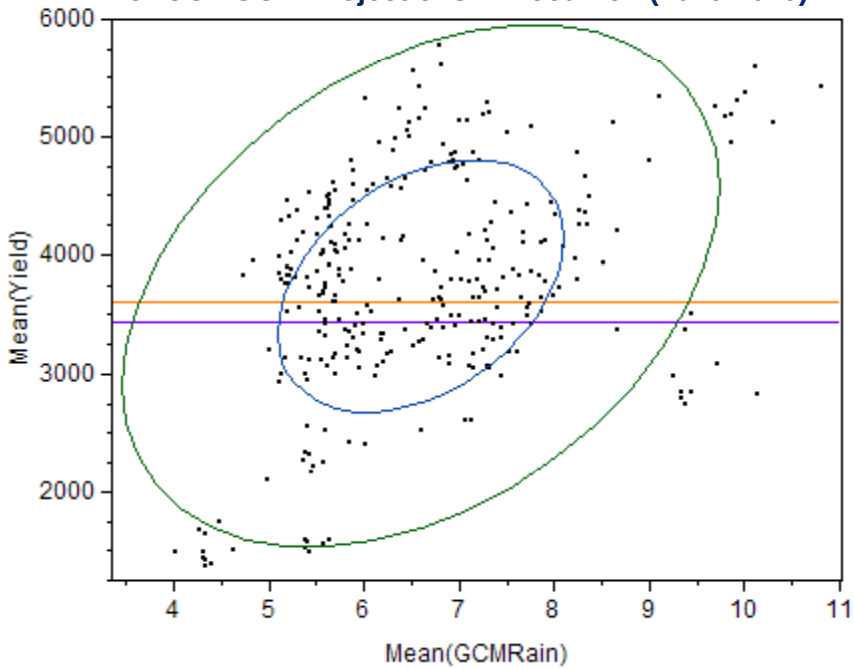


Bivariate Analysis Shows That Rainfall & Temp Do Affect GCM-Projected (2020-2049) Maize Yield

Temperature & Yield Percentages for CO2 GCM Projections in Tocumen (2020-2049)



Rainfall & Yield Percentages for CO2 GCM Projections in Tocumen (2020-2049)

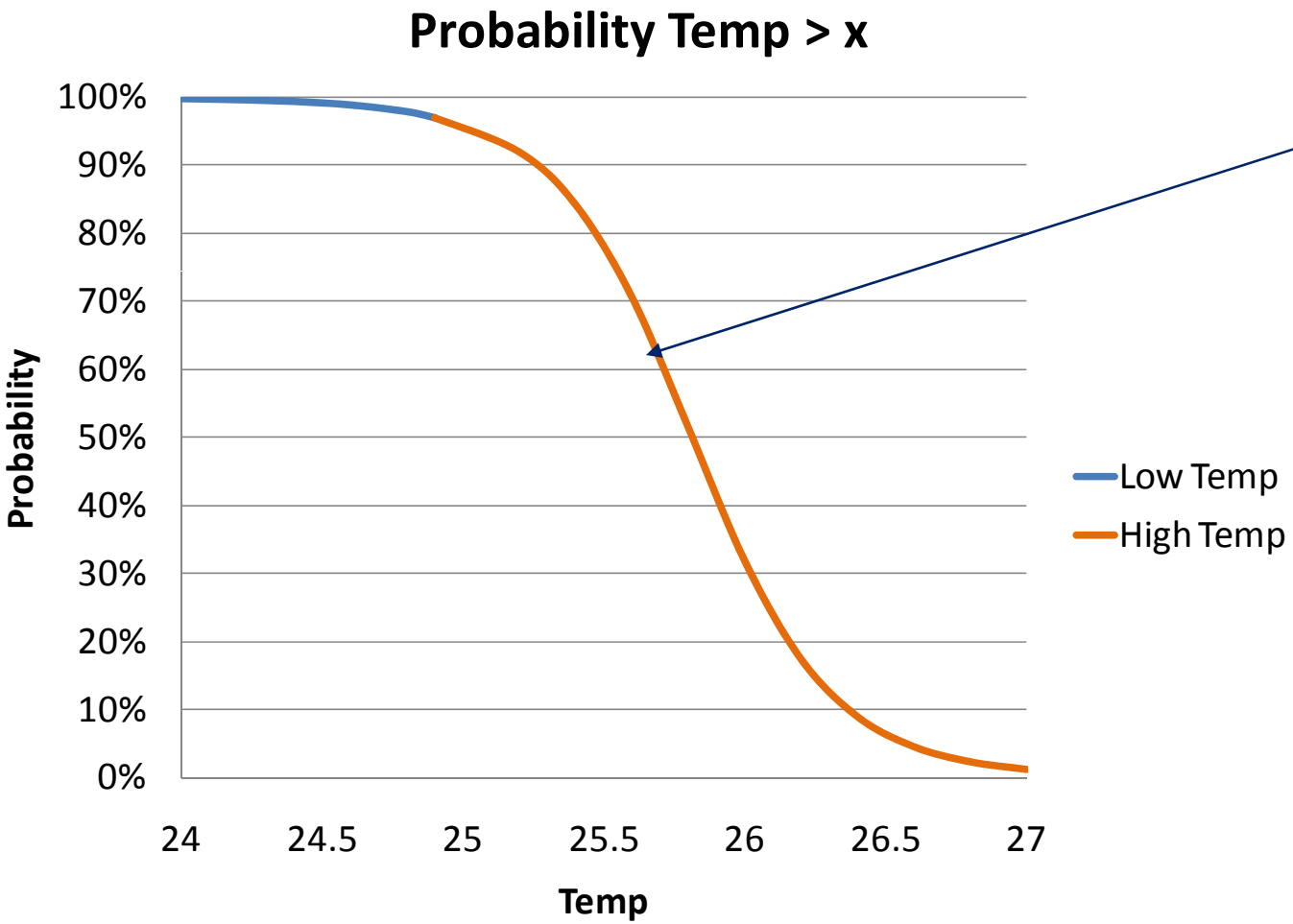


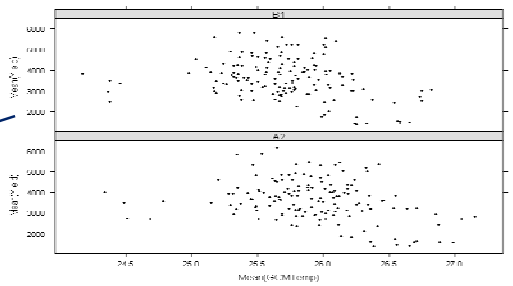
- **Follow-on analysis can determine**
  1. **optimal levels of temp and rain for maize yield**
  2. **the probability of encountering optimal conditions**

P = 0.950 Density Ellipse
P = 0.500 Density Ellipse

Baseline Average Yield = 3430
GCM Average Yield = 3607

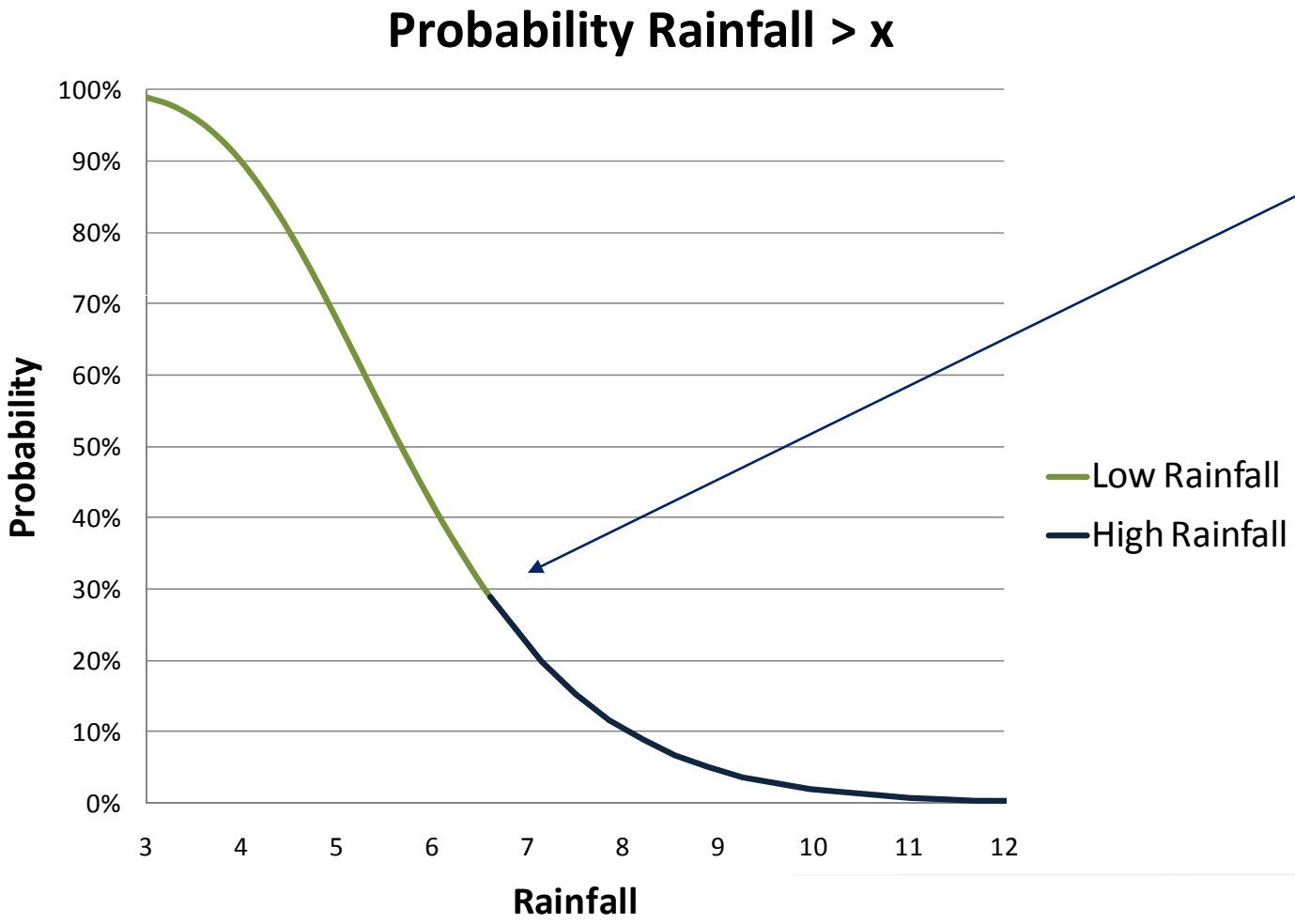
Distribution Analysis Shows That GCMs Predict Hot Temperatures During Future Years (2020-2049) In Tocumen

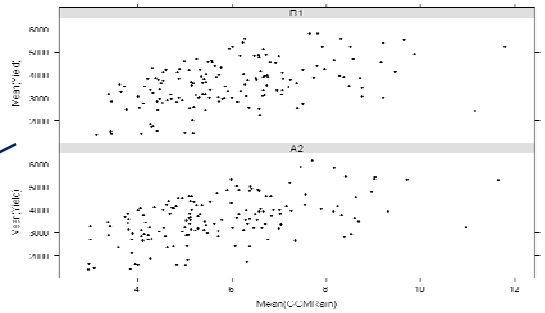




	Prb
Low Temp <24.9	3%
High Temp >24.9	97%

GCMs Predict That There Is An Almost Equal Probability Of Low Rainfall Vs High Rainfall During Future Years (2020-2049) In Tocumen





	Prb
Low Rain <6.6	71%
High Rain >6.6	29%

Rainfall & Temperature Far From Baseline Averages Impact The Probability Of Maize Yield For Any Future Year (2020-2049)

Low Temp, Low Rain	Prb
Below Baseline (3430)	79.74%
Around Baseline (+/-10%)	53.72%
Above Baseline (3430)	20.26%

Low Temp, High Rain

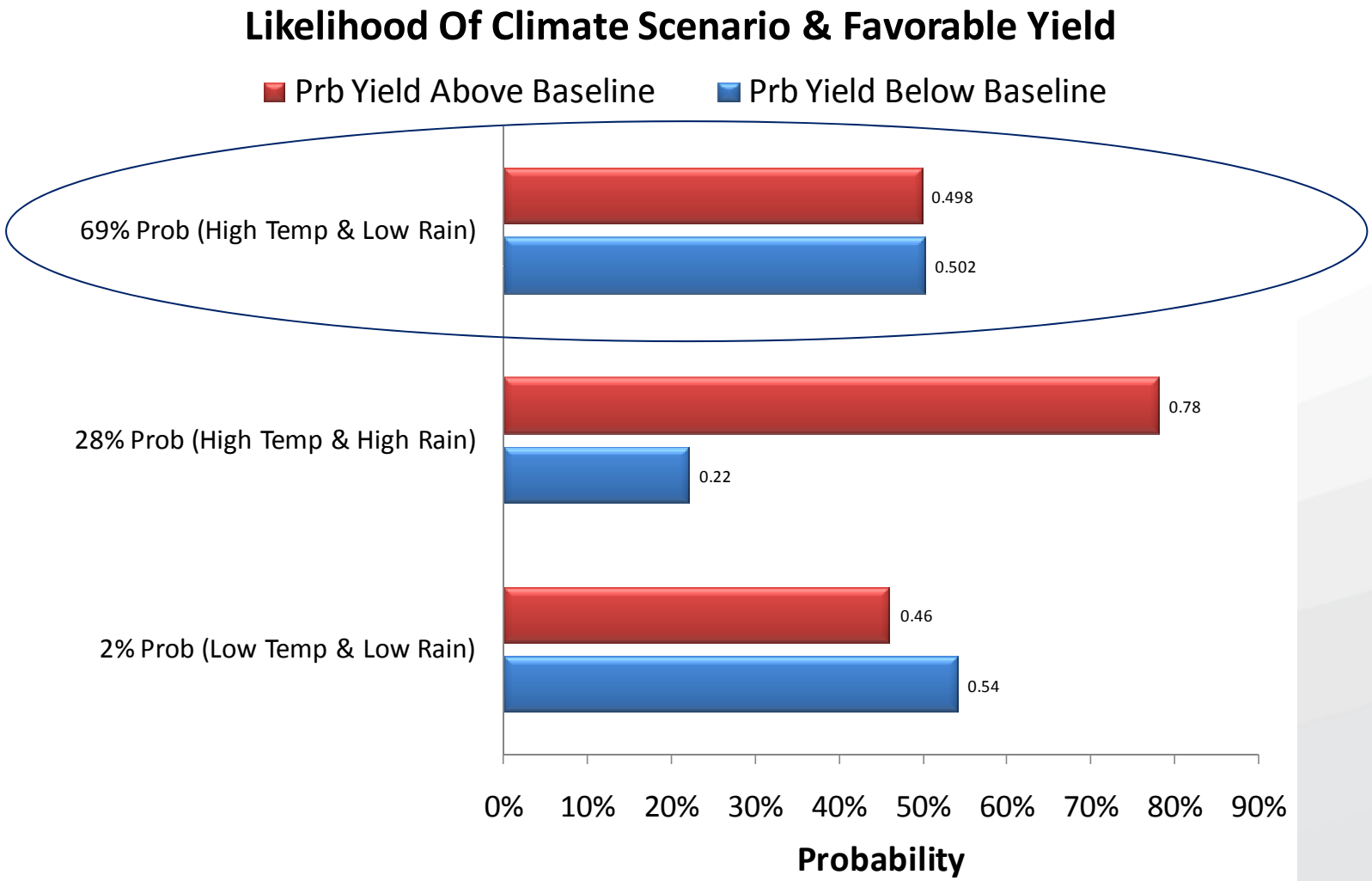
- Results are preliminary only
- Insufficient data available in this space
- A follow-on activity would be to model predictions through this space

High Temp, Low Rain	Prb
Below Baseline (3430)	50.20%
Around Baseline (+/-10%)	27.85%
Above Baseline (3430)	49.80%

High Temp, High Rain	Prb
Below Baseline (3430)	22.40%
Around Baseline (+/-10%)	19.82%
Above Baseline (3430)	77.60%

- Low Temp is defined as temp below the baseline average (24.9)
- Low Rainfall is defined as rainfall below the baseline average (6.6)

Knowing The Probability Distribution Of Temp & Rain Determines The Likelihood Of Maize Yield Scenarios (2020-2049)



Potential enhancement of decision support systems through better understanding of climate observational uncertainties and their impacts

- Development and validation of innovative integrated decision support tools
- Assessment of the success of data policies in terms of ensuring local data input to Decision Support System for Agrotechnology Transfer (DSSAT) and Mesoamerican Environmental Monitoring System (SERVIR)
- Assessment of the needs and opportunities for capacity building in Mesoamerica (e.g., which groups, subject matter, etc)
- Identification of areas where new scientific understanding is needed to improve products, assimilation systems and models, and decision support tools
- Characterize the likelihood of extreme values in factors such as rainfall and temperature, e.g. El Nino. Explore the consequences of extreme values on maize yield.
- Determine the optimal temperature range and optimal rainfall range for maize yield in a specific region
- Develop a probabilistic relationship between temperature, rainfall, and maize yield. This relationship will characterize the interaction between temperature and rainfall on maize yield. This is an improvement on the main-effects model previously built.
- Acquire raw satellite data and evaluate uncertainty in satellite measurements.