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Seasonal Prediction of Major Cereal Crop Yields in Ethiopia Using a Coupled Modeling Framework

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Objectives

I

To calibrate physically based crop models at two different spatial scales for application in seasonal prediction of crop yield in the Blue Nile Basin of Ethiopia

II

To identify the most influential climate variables for crop yield in different regions of Ethiopia (which will then guide the strategic development of seasonal climate prediction)

Outline

Background, Data and Method

Crop yield simulation and forecast at the site scale

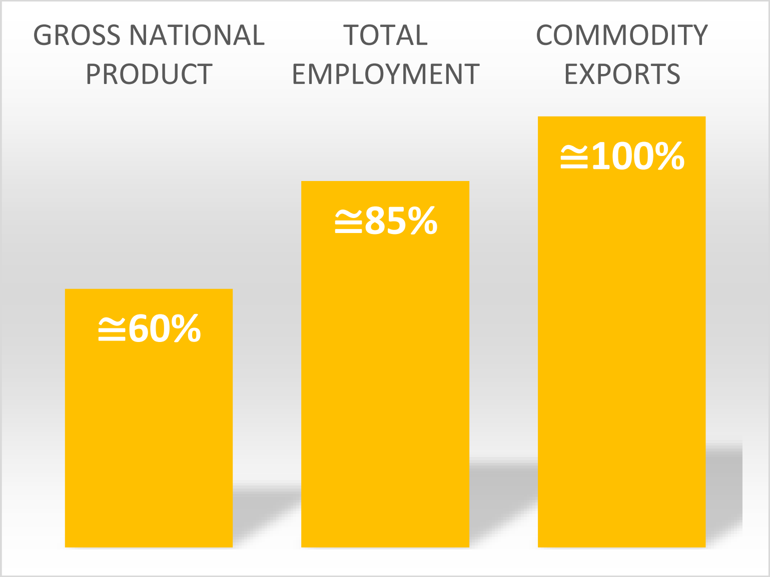
Crop yield simulation and sensitivity at the AEZ scale

Crop-hydrologic coupled modeling framework

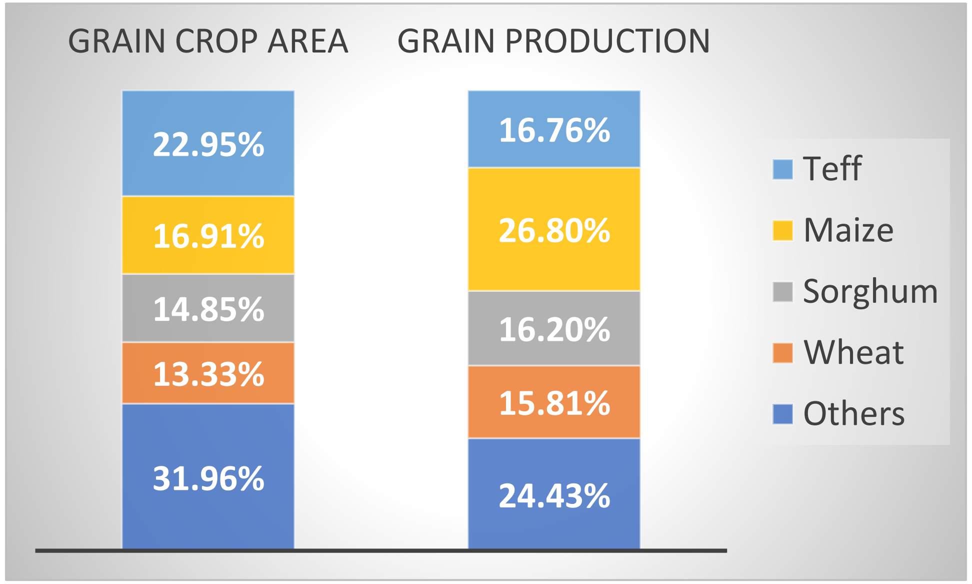
Summary

Background

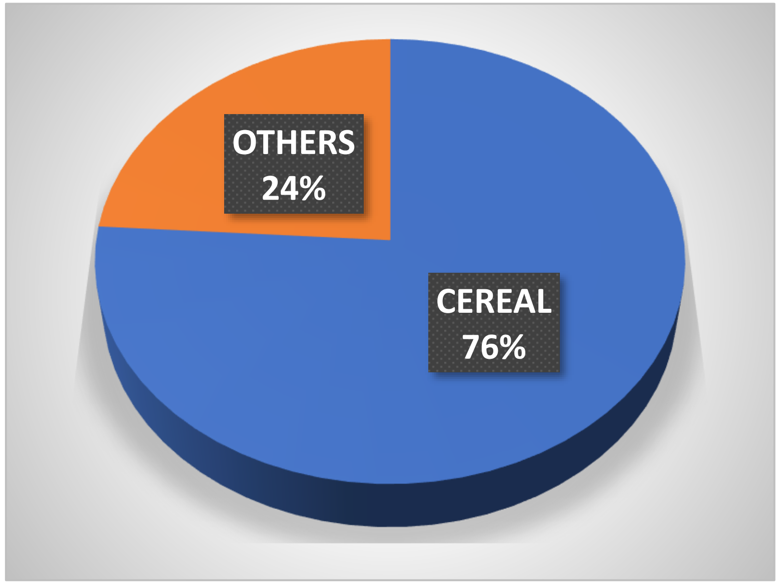
Role of Agriculture



Major Cereal Crops



$575M for Food Import



Smallholder Farming System

Methods

Decision Support System for Agrotechnology Transfer (DSSAT)

A process-based crop model that integrates crop physiology and phenotype, weather and soil data, and crop management strategies, to simulate growth, development, and yield of a crop growing on a uniform area of land under prescribed or simulated management and changes in soil water, carbon, and nitrogen during the simulation process.

DSSAT does not include any model for teff

Five cereal crops: barley, maize, millet, sorghum, wheat

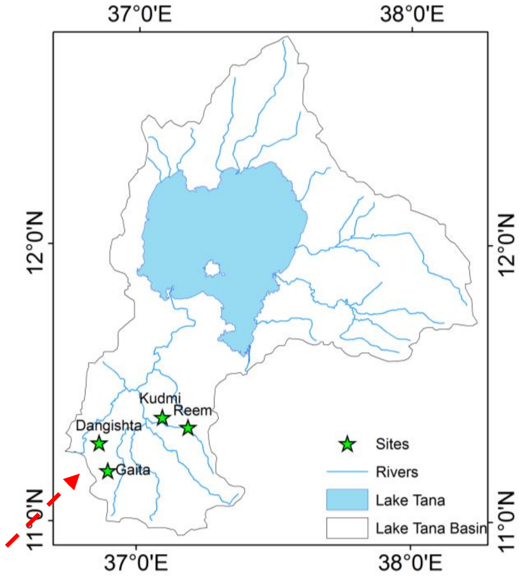
All crops are rainfed in simulation

Time range: 1979 – 2014 (36 years)

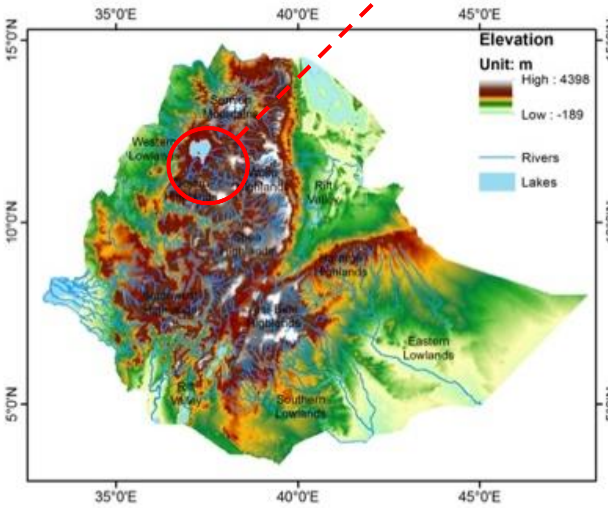
Tow scales:

- Site scale
- Agroecological Zone (AEZ) scale (5 arc-minute)

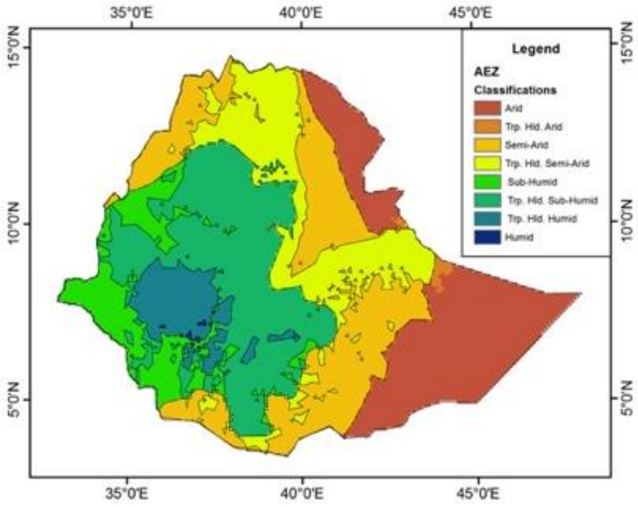
Sites location



Topographic map



AEZ classification



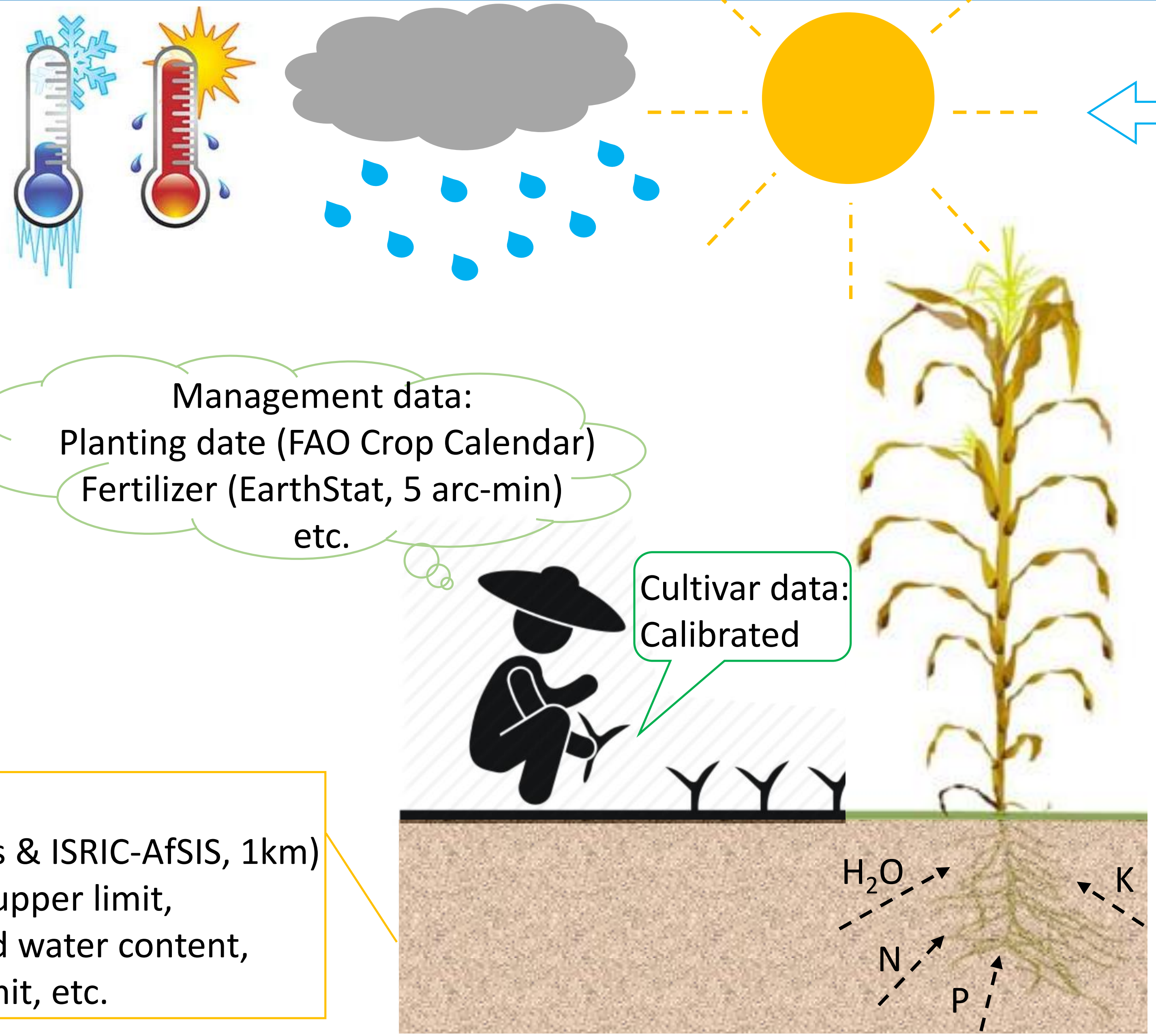
Data

Weather data:
Solar radiation & temperature
(ERA-Interim, 0.25 degree)
Precipitation (MSWEP, 0.25 degree)

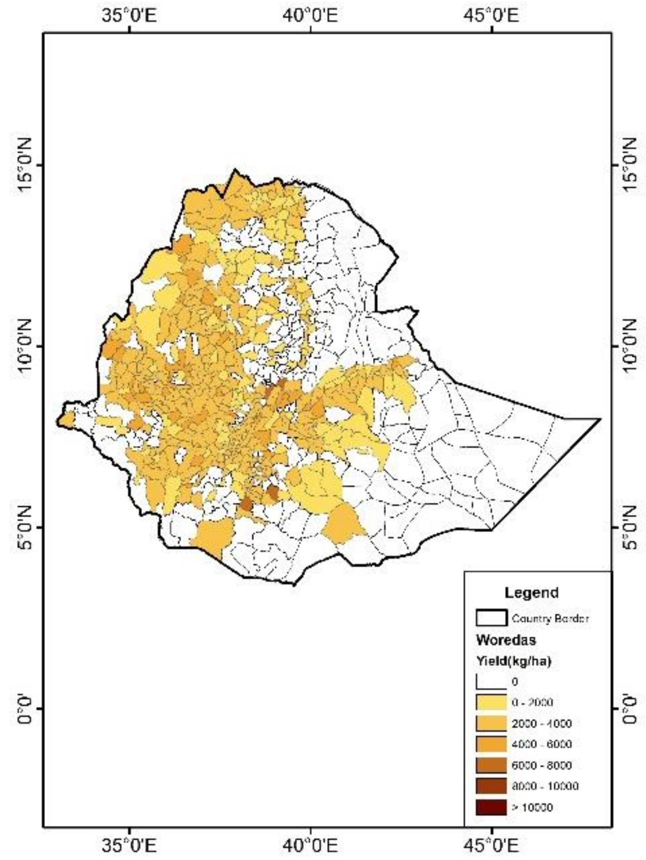
Management data:
Planting date (FAO Crop Calendar)
Fertilizer (EarthStat, 5 arc-min)
etc.

Cultivar data:
Calibrated

Soil data:
(SoilGrids & ISRIC-AfSIS, 1km)
Drained upper limit,
Saturated water content,
Lower limit, etc.



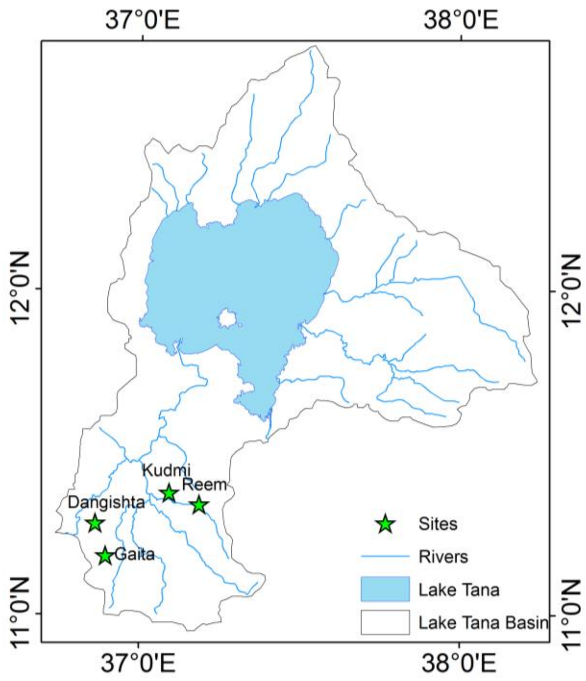
Observational data
(Ethiopia’s Central Statistics Authority)



Crop yield simulation and forecast at the site scale

Model calibration

Aiming at minimize the simulation bias over the four sites



$$AB = Yield_{sim} - Yield_{obs}$$

$$RB = AB/Yield_{obs}$$

Sorghum is excluded

Calibration period: 2004 & 2007-2013

Crop yields at four sites during the calibration period

Crop yield simulation and forecast at the site scale

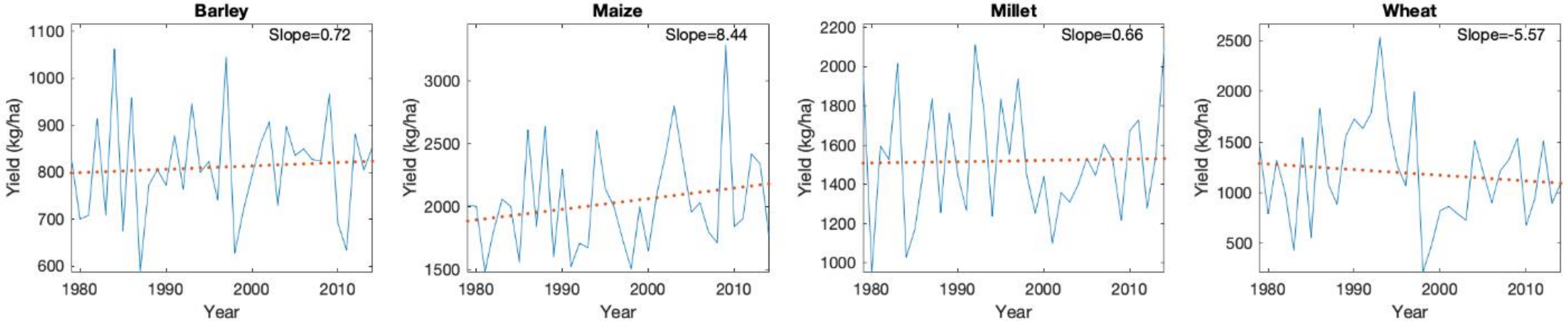
Challenges

- Observational record is often not long enough to support robust correlation analysis
- Seasonal prediction may not provide sufficient climate information to run a process-based model like DSSAT
- Local agencies may not have the capacity to run a process-based model

To address these challenges we conduct a long term DSSAT simulation to support statistically based analysis

The calibrated model was further run for 36 years

Interannual variability and trend of crop yields averaged across the four sites



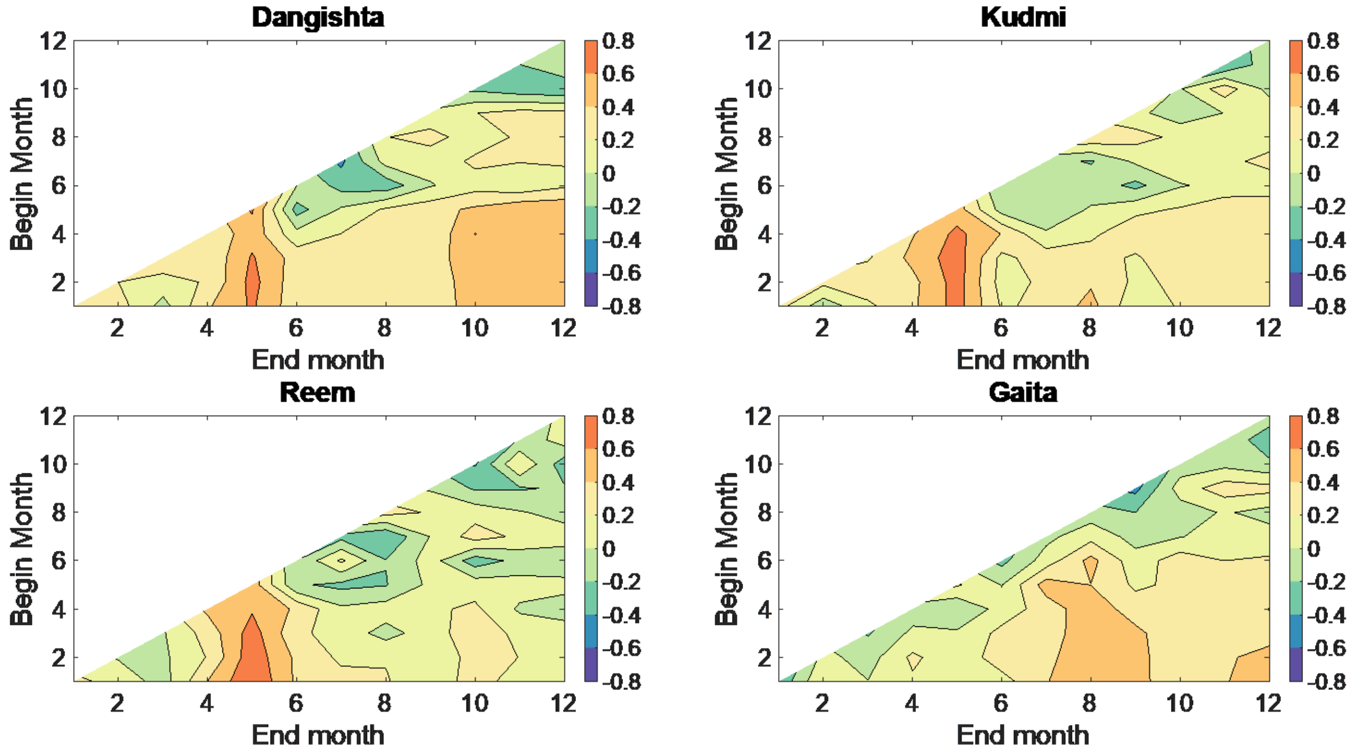
Crop yield simulation and forecast at the site scale

The analog model is developed based on the DSSAT-simulated crop yield and climate during the 36-year period of 1979-2014, and the model can be used for both forecast and hindcast

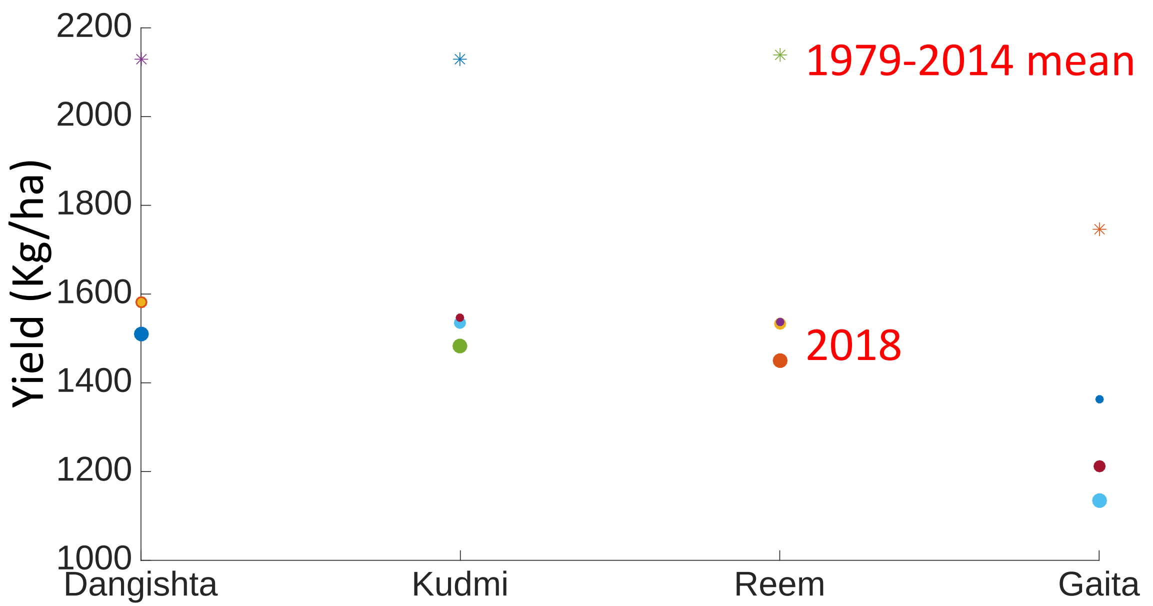
Precipitation from January to May is used for the analog year selection

Use maize as an example:

Analog hindcast skill

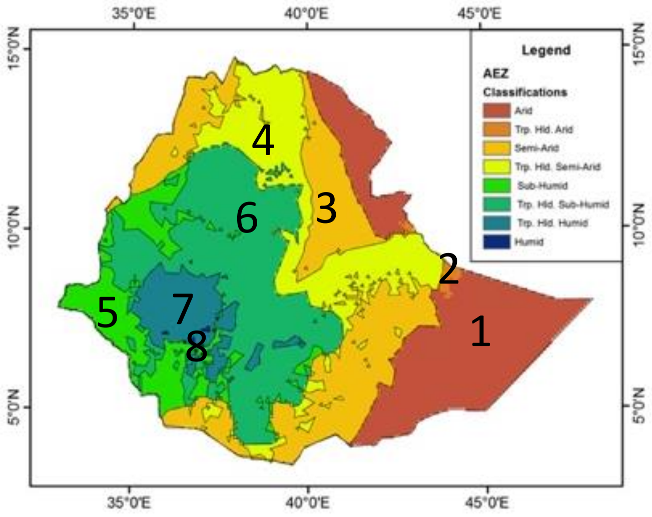


Forecasted crop yield for 2018



Crop yield simulation and sensitivity at the AEZ scale

AEZ classification



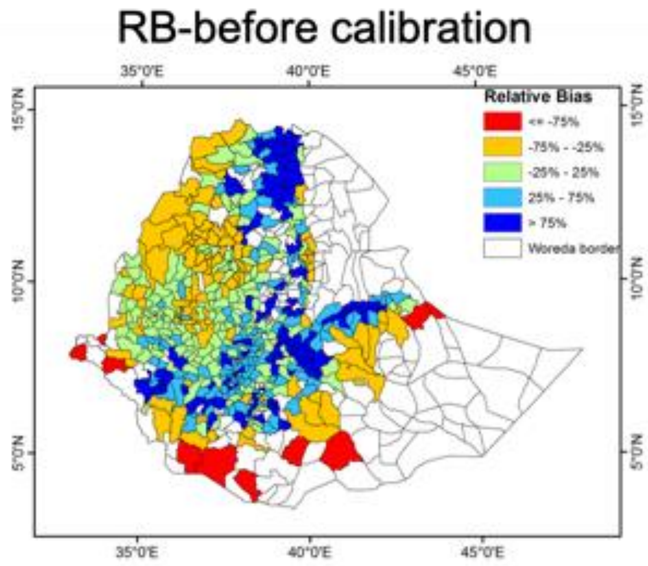
Spatially averaged RB for maize simulation in each AEZ before and after calibration

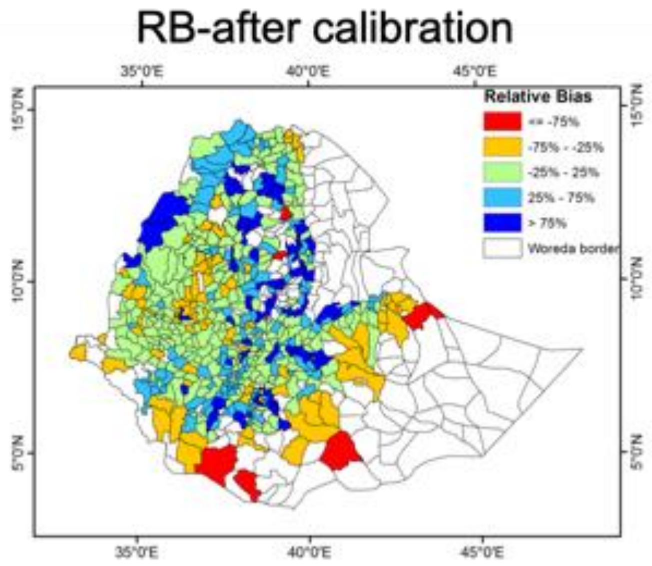
	Before Calibration	After Calibration
AEZ3	-18.25%	0.04%
AEZ4	46.41%	-1.94%
AEZ5	11.13%	-2.44%
AEZ6	36.91%	-0.71%
AEZ7	41.35%	-0.31%

Spatial resolution:
5 arcminute

Model outputs are then aggregated to woreda and AEZ level for comparison

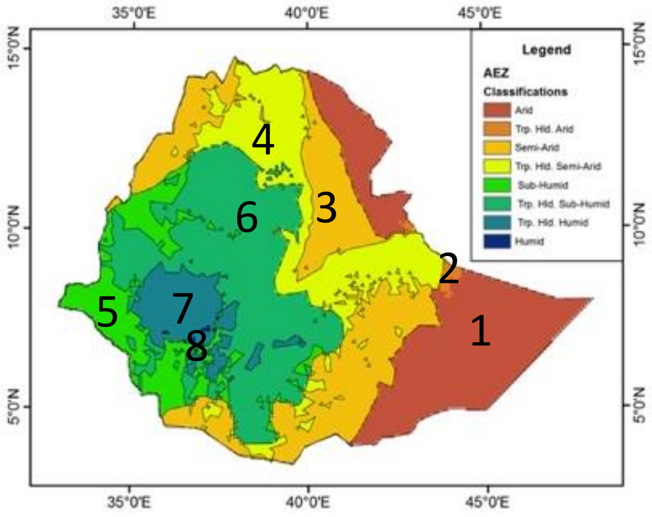
Model biases before and after calibration for maize in woreda level





Crop yield simulation and sensitivity at the AEZ scale

AEZ classification



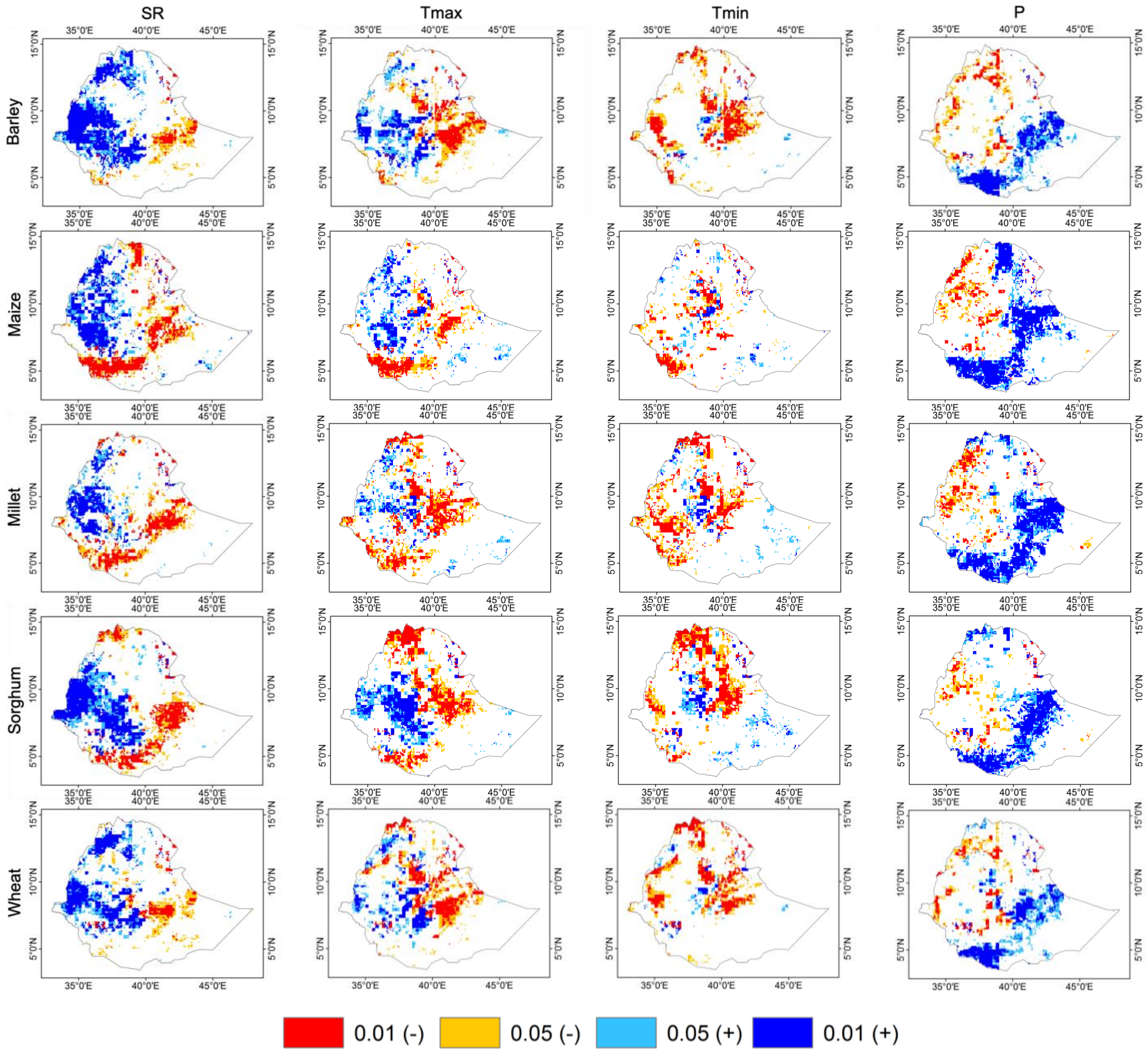
RB for the calibration and validation of crops in different AEZs

Crop type	AEZ3	AEZ4	AEZ5	AEZ6	AEZ7
Barley	-8.54%	0.43%	3.94%	0.90%	1.99%
	11.63%	0.18%	-9.09%	1.76%	2.90%
Maize	0.04%	-1.94%	-2.44%	-0.71%	-0.31%
	1.93%	-0.27%	-1.71%	0.72%	-1.48%
Millet	-0.62%	1.11%	-3.93%	1.29%	1.77%
	-3.44%	0.74%	0.20%	-0.07%	-0.88%
Sorghum	-0.97%	-0.42%	1.89%	-1.49%	2.37%
	0.33%	0.14%	-0.87%	-1.22%	0.21%
Wheat	-6.93%	-0.89%	2.55%	-3.35%	-1.47%
	7.85%	-0.44%	-2.58%	-2.68%	-0.90%

Note: for each crop, the first row stands for calibration, and the second row stands for validation.

Crop yield simulation and sensitivity at the AEZ scale

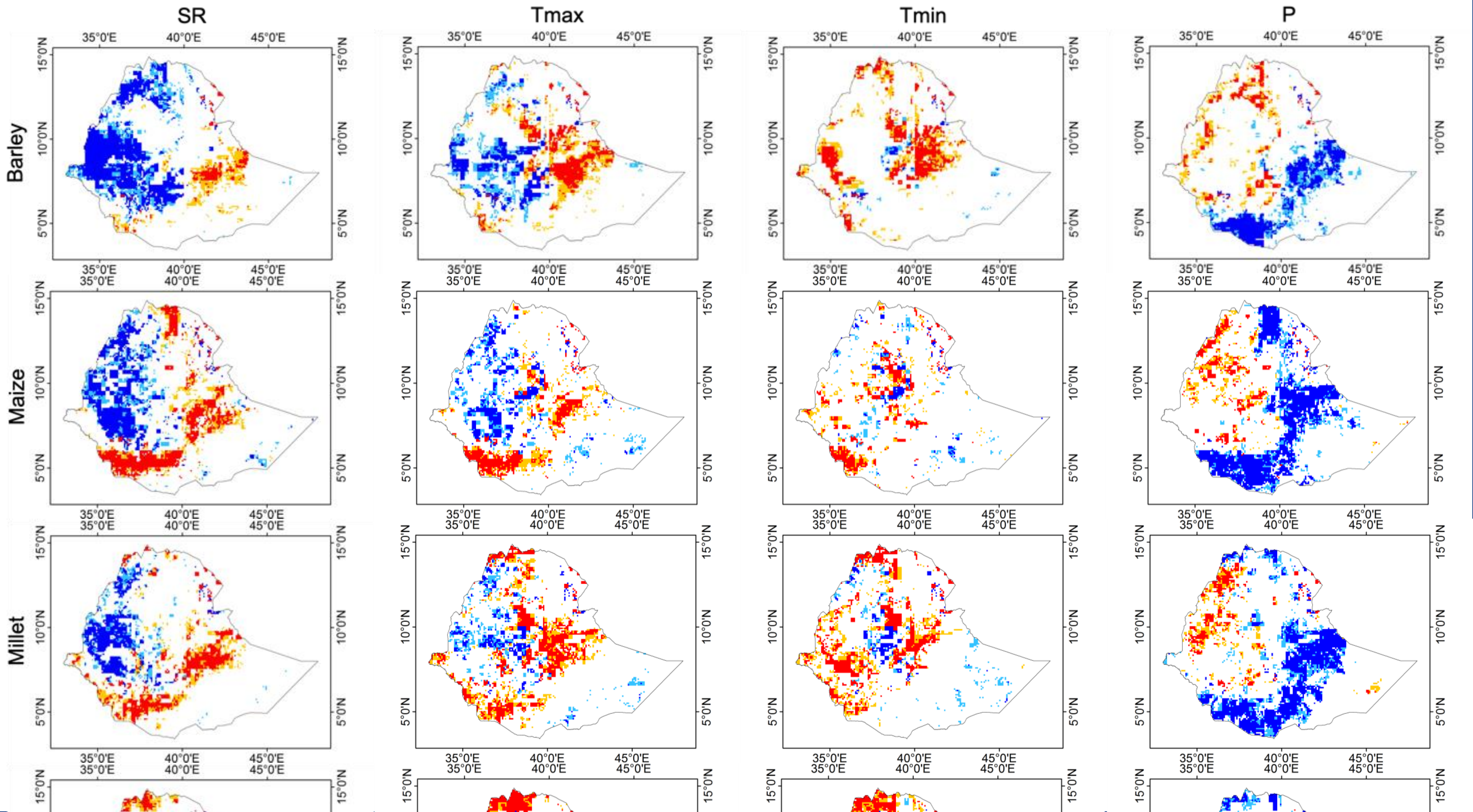
Significant correlation coefficient between crop yields and climate variables



Note:

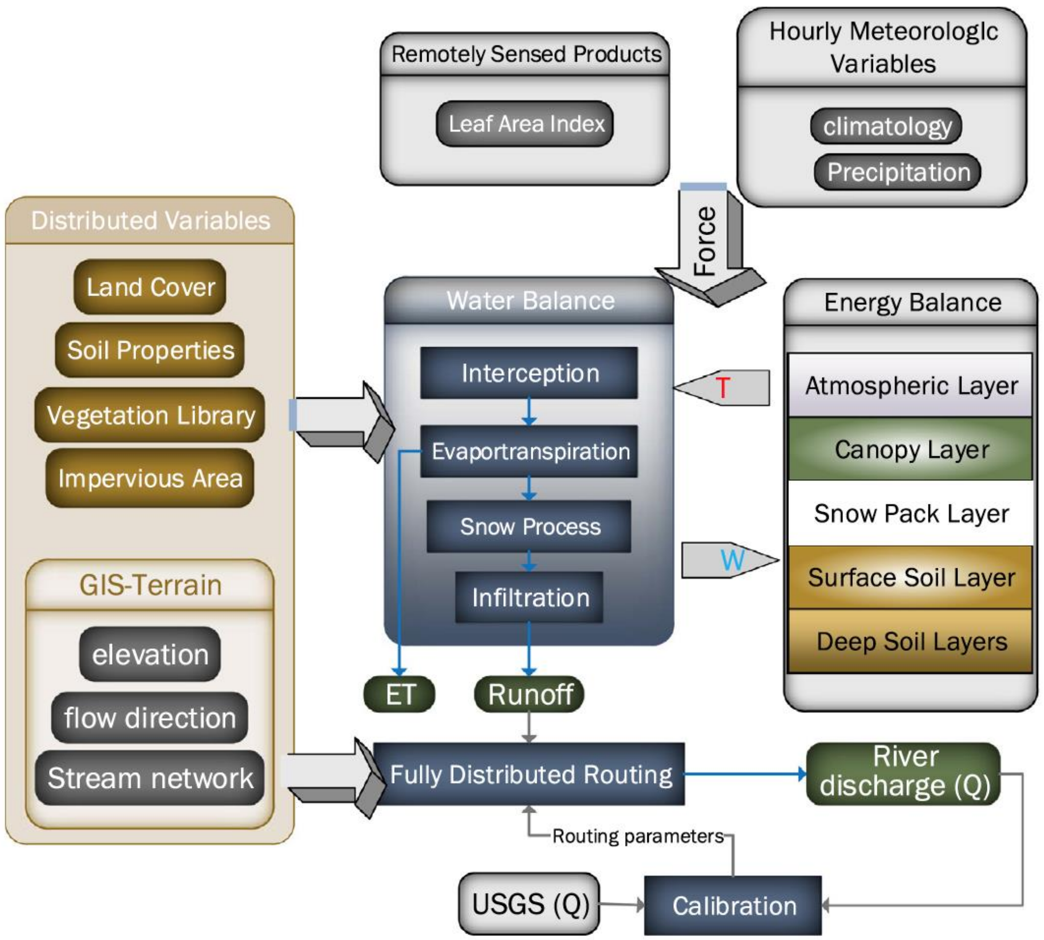
\+ positive correlation

\- negative correlation


SR
Tmax
Tmin
P
Barley
Maize
Millet
35°0'E
40°0'E
45°0'E
15°0'N
10°0'N
5°0'N

Crop-hydrologic coupled modeling framework

Structure of Coupled Routing and Excess STorage (CREST) model



Soil moisture simulation scheme

DSSAT

Tipping bucket approach

CREST

Infiltration within a layer:
Green-Ampt Model

Percolation from upper to lower layer:

$$w_{perc,ly} = SW_{ly,excess} \cdot \left[1 - exp\left(\frac{-\Delta t}{TT_{perc}}\right)\right]$$

Replace DSSAT daily soil moisture with CREST daily soil moisture

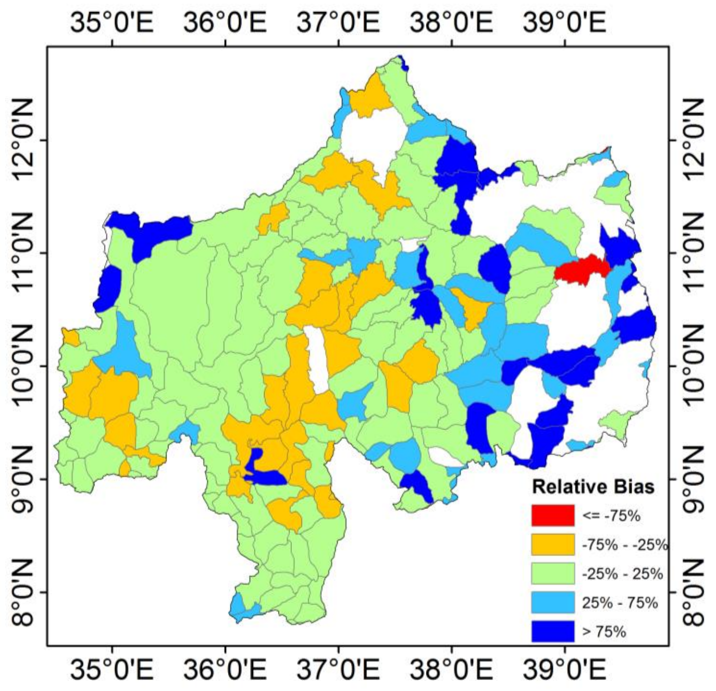
Crop-hydrologic coupled modeling framework

Application of coupled modeling framework in Abbay Basin, Ethiopia and its performance

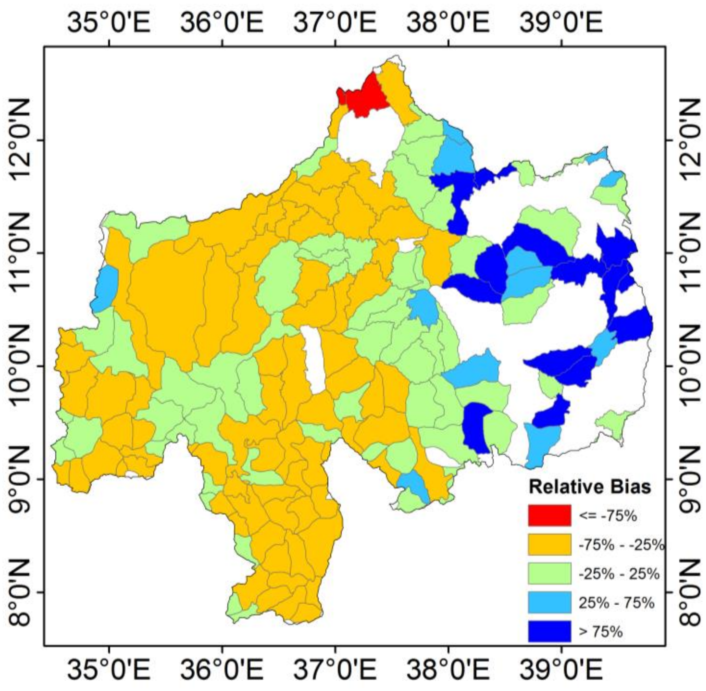
The coupled model tends to have larger underestimation areas of crop yield

Use maize as an example:

DSSAT



DSSAT-CREST



Summary

- The correlation between yield and climate shows a similar distribution pattern among different crops.
- Crop yield in the west part of the country is significantly positively correlated with solar radiation and maximum temperature, but negatively correlated with precipitation.
- Crop yield in the east and south part of the country is significantly positively correlated with precipitation, but negatively correlated with solar radiation, maximum temperature and minimum temperature.
- The soil moisture simulation scheme in DSSAT is sufficient in modeling crop yield.
- Based on the precipitation from January to May, analog approach does a good job in crop yield hindcast.