Climate Trends and Global Crop Yields

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The question

Is anthropogenic climate change enhancing the risk of crop yields experiencing a significant slowdown, due to adverse temperature and precipitation trends in the next ten or twenty years?
The recipe

Characterizing **possible outcomes** in temperature and precipitation trends over the next 10 or 20 years from climate model output.

Translating those projections into changes in crop yields.

Assessing the risk of significant slowdowns by focusing on the **chances** of decrease in yields by 5% or 10%.

Comparing the results to what would be happening in the absence of anthropogenic climate change.
Characterizing **possible outcomes** in temperature and precipitation…

**Experiments**

Pre-industrial control experiment with NCAR’s model: no external forcings, i.e. a look at climate undisturbed.

Large ensemble: 40 initial condition ensemble members from NCAR’s model, run under a “business as usual” scenario. Many possible realizations of climate for the next 10 or 20 years according to a particular model.

CMIP5 experiments: 39 models running under “business as usual”. Many possible realizations of climate for the next 10 or 20 years according to an ensemble of models.
Initial-Condition Ensembles are intended to characterize uncertainty due to the internal variability of the system.

Multi-Model Ensembles help us to uncover and characterize this structural uncertainty.

The expectation is that when looking at the next 10 or 20 years the two types of ensemble should give us a similar picture of the range of temperature and precipitation trends we can expect.

They should however say something different from the control experiments.
Translating those projections into changes in crop yields

Empirical models of Yields vs. Temperature & Precipitation

Wheat
Yield change per degree of warming: -6%

Maize
Yield change per degree of warming: -7%

Wheat
Yield change per 10% increase in P: -1% (not sig.)

Maize
Yield change per 10% increase in P: 1.5% (not sig.)
Each dot on the graphs:

Global yield of Wheat (Maize) (annual statistic, FAO)
Average temperature (and precipitation)
aggregated over all barley-growing regions,
for the crop-, region-specific growing season

Except, these are actually changes from year to year
(first difference time series).

\[ \Delta Y_i = \beta \Delta T_i + \gamma \Delta P_i + \varepsilon_i \]
We estimate

$$\Delta Y_i = \beta \Delta T_i + \gamma \Delta P_i + \varepsilon_i$$

on the basis of observed data (1962-2012)

$$\left( \hat{\beta}, \hat{\gamma} \right)$$

Temperature coefficient highly significant

Precipitation coefficient non significant
We will then plug in

\[(\Delta T_i, \Delta P_i)\]

distributed according to the joint output from climate models ‘experiments’ (several hundred bootstrapped trends in T and P in each case).

We thus obtain a distribution for

\[\Delta \hat{Y}_i\]

the change in yield.
Uncertainties in crop response to climate variability
Uncertainties in crop response to climate variability

\((\hat{\beta}_1, \hat{\gamma}_1)\)
Uncertainties in crop response to climate variability

\[(\hat{\beta}_2, \hat{\gamma}_2)\]
Uncertainties in crop response to climate variability

\[ \hat{\beta}_3, \hat{\gamma}_3 \]
Uncertainties in crop response to climate variability

\((\hat{\beta}_4, \hat{\gamma}_4)\)
Uncertainties in crop response to climate variability

$(\hat{\beta}_5, \hat{\gamma}_5)$
Uncertainties in crop response to climate variability

\[(\hat{\beta}_6, \hat{\gamma}_6)\]
Uncertainties in crop response to climate variability

\[ (\hat{\beta}_7, \hat{\gamma}_7) \]
Uncertainties in crop response to climate variability

$(\hat{\beta}_8, \hat{\gamma}_8)$
Uncertainties in crop response to climate variability

\((\hat{\beta}_9, \hat{\gamma}_9)\)
Uncertainties in crop response to climate variability

\[ \begin{pmatrix} \hat{\beta}_10 \\ \hat{\gamma}_10 \end{pmatrix} \]
Areas where crops are grown and month of harvest

We aggregate observations and GCM output (temperature and precip) over these areas and over ‘growing seasons’
Joint changes in Temperature and Precipitation according to the different experiments

Trends over the next 10 years
Joint changes in Temperature and Precipitation according to the different experiments

Trends over the next 20 years
From an ensemble of climate projections to an ensemble of Yield change projections

\[
\Delta Y_1 = \hat{\beta} \Delta T_1 + \hat{\gamma} \Delta P_1
\]

\[
\Delta Y_2 = \hat{\beta} \Delta T_2 + \hat{\gamma} \Delta P_2
\]

\[
\Delta Y_3 = \hat{\beta} \Delta T_3 + \hat{\gamma} \Delta P_3
\]

\[
\Delta Y_{1000} = \hat{\beta} \Delta T_{1000} + \hat{\gamma} \Delta P_{1000}
\]
Probability distributions of yield changes in the face of an ensemble of climate projections

Maize, 10 Year Trends

- Climate Variability Only
- Climate Variability + Change, CCSM
- Climate Variability + Change, CMIP5

Wheat, 10 Year Trends

Maize, 20 Year Trends

Wheat, 20 Year Trends
Focusing on the risk of significant slowdowns

Change of Yield Impacts of $-5\%$ or Worse Over 10 year Period

- ClimVar Only
- ClimVar + Change, CCSM
- ClimVar + Change, CMIP5

Change of Yield Impacts of $-10\%$ or Worse Over 20 year Period

- ClimVar Only
- ClimVar + Change, CCSM
- ClimVar + Change, CMIP5
Conclusions

Using large ensembles of climate model output we characterize a range of possible outcomes in temperature and precipitation trends over the next 10 or 20 years. We compare climate with and without the anthropogenic effect of GHG emissions.

We estimate empirical models of the relation between temperature and precipitation and crop yields at the global scale for two major crops, wheat and maize.

Changes in temperature and precipitation over the next 10 or 20 years have a range of effects, but we focus on the chances of “significant slowdowns”, which we define as a negative change of 5% or 10% over 10 or 20 years respectively (which would half the expected growth of production).

We find that anthropogenic climate change increases the chances of such slowdowns considerably, for both crops, but in particular for maize.