Using damage functions to estimate consequences from pests, diseases and climate change

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Overview

- Why estimate damage functions?

- Estimating pest damages

- Estimating climate damages to crops

- Challenges

- Extensions and limitations

Why estimate damage functions?

- We want to understand the potential consequences of a hazard that could occur over time/space – and the benefits of reducing this risk

- Damage functions allow estimates of damage from contexts with data to be transferred to 'new' contexts

- Use cases:
  - Value of biosecurity systems in Australia and New Zealand (MPI, DAFF)
 - Biosecurity risks from changing climate and trade patterns (21B, Scion)

Rice blast, Philippines, IRRI (CC)

Lower Nyando, Kenya, CGIAR Climate (CC)

How to estimate damage functions?

- Theoretical relationship between hazard and damage

- Benefit transfer techniques

- Aggregate data from multiple studies or expert elicitation

- Fit damage-hazard model from data

- Meta-analysis/meta-regression

- Predict fitted model on prediction data – to 'new' hazards, 'new' locations etc.

Aggregate data

Fit model

Predict
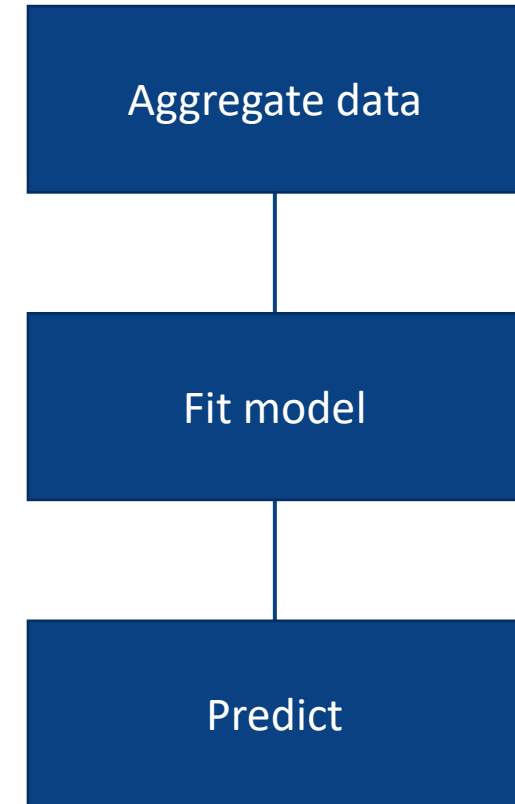
Estimating pest damages, in theory

- Damages can vary with:
  - Plant injury
  - Area occupied by pest
  - Pest population density
- In practice, how damages are modelled depends on theory, spatial scale, data availability and other factors
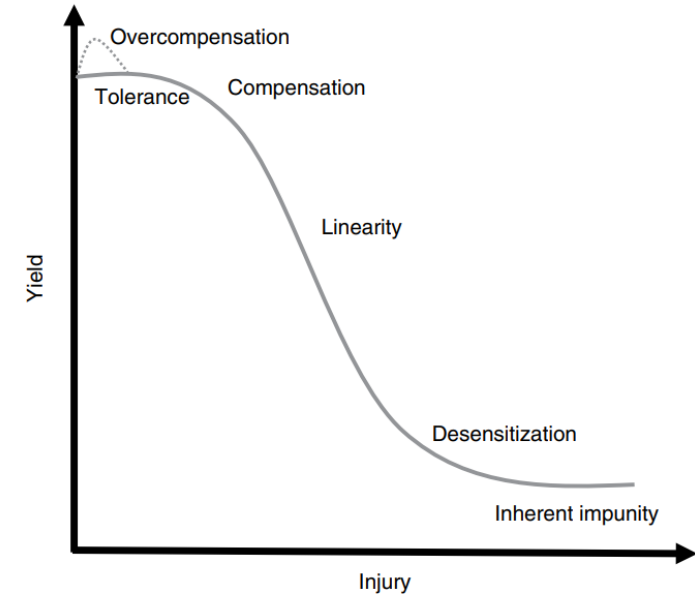

Fig. 7.4. Relationship between yield and injury triggered by pests. (Adapted from 'The damage curve – the relationship between yield and injury' from *Economic Thresholds for Integrated Pest Management* edited by Leon G. Higley and Larry P. Pedigo by permission of the University of Nebraska Press. Copyright 1996 by the University of Nebraska Press.)

Value of Biosecurity System Project damages

- Natalie Stoeckl, Aaron Dodd, John Baumgartner, Tom Kompas

- Portfolio asset damages

- Non-portfolio asset damages

  - ABARES expert-elicited 'relative severity' scores for 40 hazard functional groups

  - 66 point estimates from 41 studies on absolute relative damage estimates (for subset of pest species)

  - Assign distribution to elicited scores

Aggregate data:
Non-market values from literature

Model:
Logarithmic functional form

**Predict:**
On expert elicited scores

Table 11: Estimated impact (proportional decline in the value of asset flows) of each functional group on assets following the extended CICES classification.

#	Functional group	Provisioning (Non-Portf)	Regulating	Cultural	Domestic Animals	Infrastructure
1	AGM	0.0633	0.227882	0.338578	0	0
2	Animal other bacteria	0	0	0	0.015091	0
3	Animal other micro other	0.004361	0.010731	0	0.0633	0
4	Animal other virus	0	0	0	0.0633	0
5	Avian virus	0.015091	0.017363	0.045822	0.015091	0

Stoeckl et al. 2020 Values and vulnerabilities: what are the values of the assets that are protected by Australia's biosecurity system and how vulnerable are they to incursions?

Estimating climate damages to crops

- Yields change in response to changing climate and biotic interactions

- Many variables affect plant growth: air temperature, water, humidity, CO_2, ozone, nutrients, soil management and more

- Optimal temperature ranges for vegetative and reproductive development

- Crop models can be used to understand these relationships and predict yield
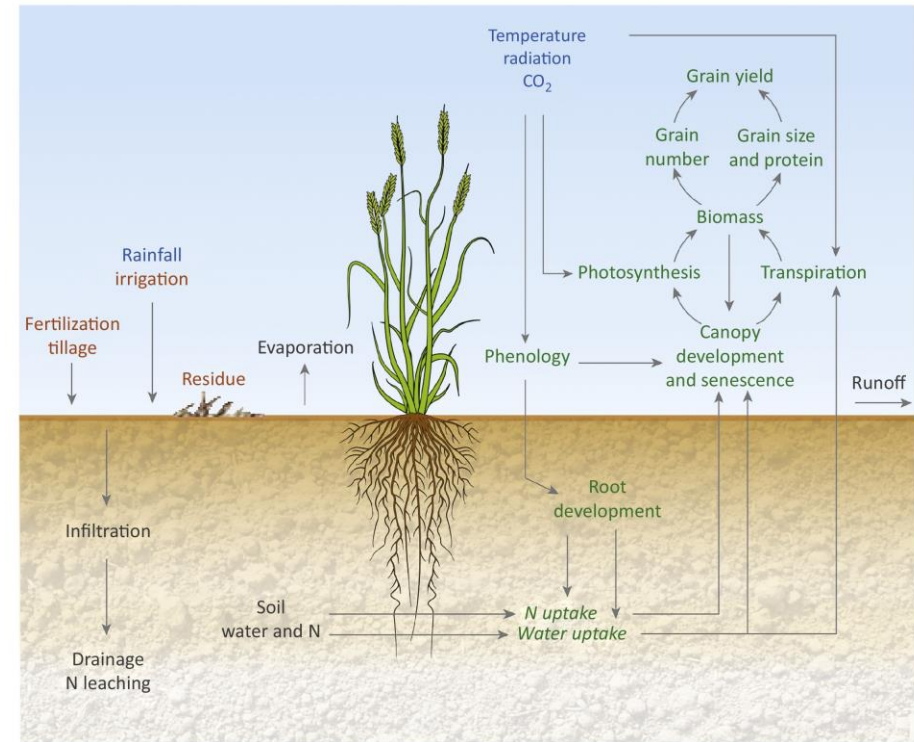
Simplified Framework of a Wheat Crop Model: Chenu et al 2017, Contribution of Crop Models to Adaptation in Wheat, Trends in Plant Science Vol. 22 Issue 6

Estimating climate damages to crops

Steps

- Aggregate and groom 13,000+ estimates from 89 studies (CGIAR database)

- Impute missing values (MICE)

- Formal meta-analysis

- Fit Generalised Additive Mixed Model (GAMM) with study and country random effects
  - Variables: Mean baseline growing season temperature ($\circ$C) and precipitation (mm/month), change in temperature (%), change in precipitation (mm), f(CO_2), adaptation, and interaction terms

- Estimate parameters of general damage function

- Model cross-validation

- Predict estimated damage function on global gridded data for $0.5\circ$ x $0.5\circ$ damage predictions

Meta-analysis

- Nested structure in data

- Multiple studies

- Multiple countries

- Other levels...

- Account for dependencies within same study and same country

- Meta-regression
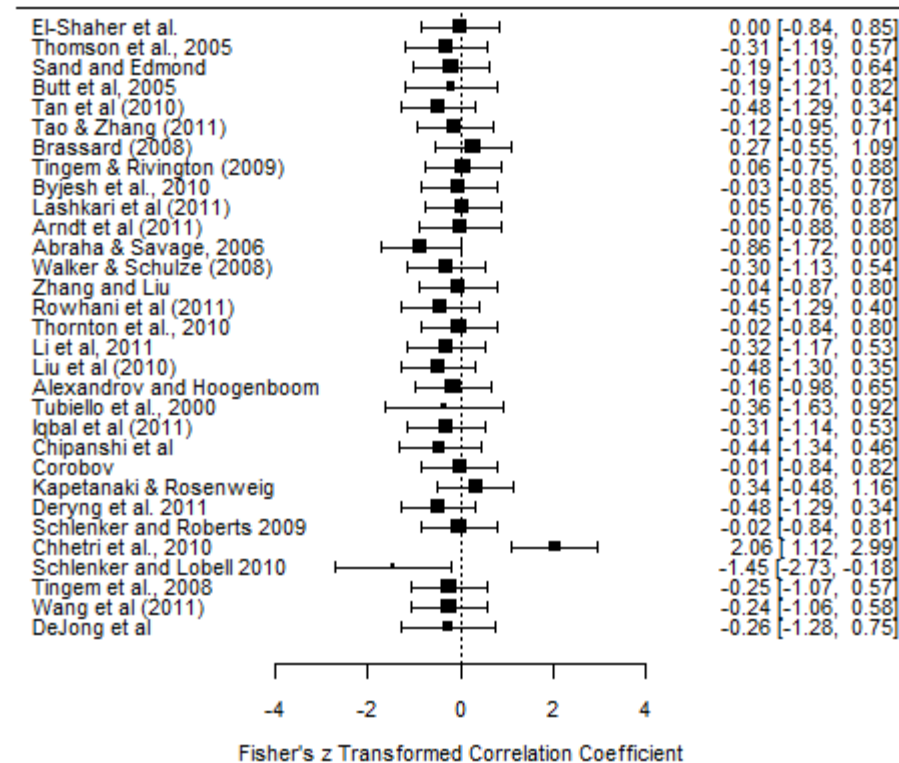
Forest plot of correlations between temperature and yield change for maize response data (imputed dataset #1)

Climate crop damage functions

- Yields change in response to temperature change – these are relative but we can extend to absolute yield changes

- Responses vary at different values of baseline temperatures and precipitation, and precipitation change
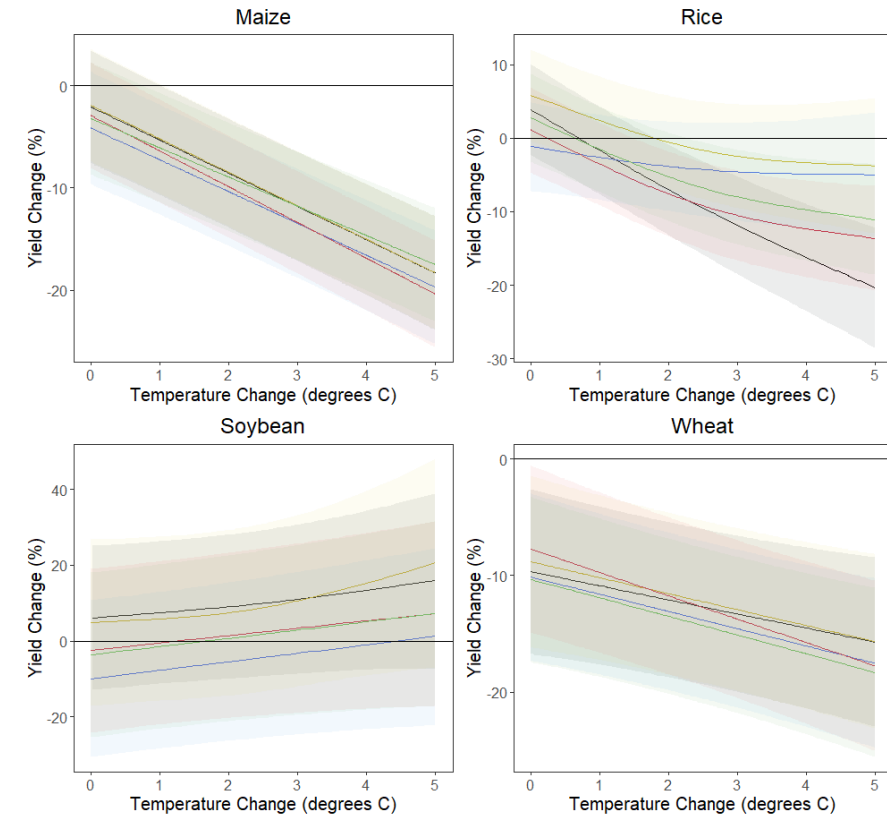
Response functions conditioned on zero change in rainfall, no adaptation, no change in CO2, and median baseline temperatures

Global crop damage predictions

- Predict estimated damage functions on prediction data

- Prediction data are variables in the damage function, estimated at 0-5 degrees of mean global warming from baseline period 2015-2020

- Predicted yield losses used in climate and trade modelling (21B)
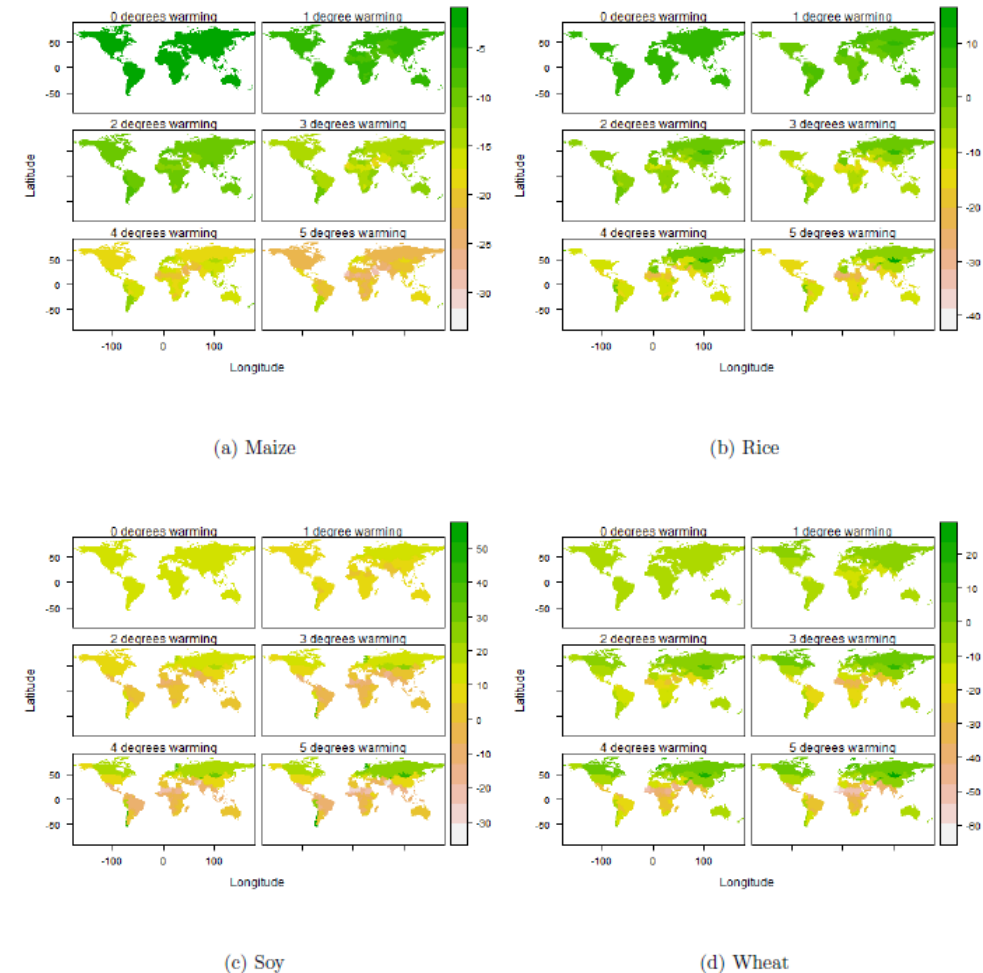
- Implications for food security and trade patterns

(a) Maize

(b) Rice

(c) Soy

(d) Wheat

Figure 1: Median country production-weighted average predictions pooled across imputation-specific predictions from 2015-20 baseline

Global crop damage predictions (gridded)

- Predict estimated damage functions on prediction data

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- Predicted yield losses used in climate and trade modelling (21B)

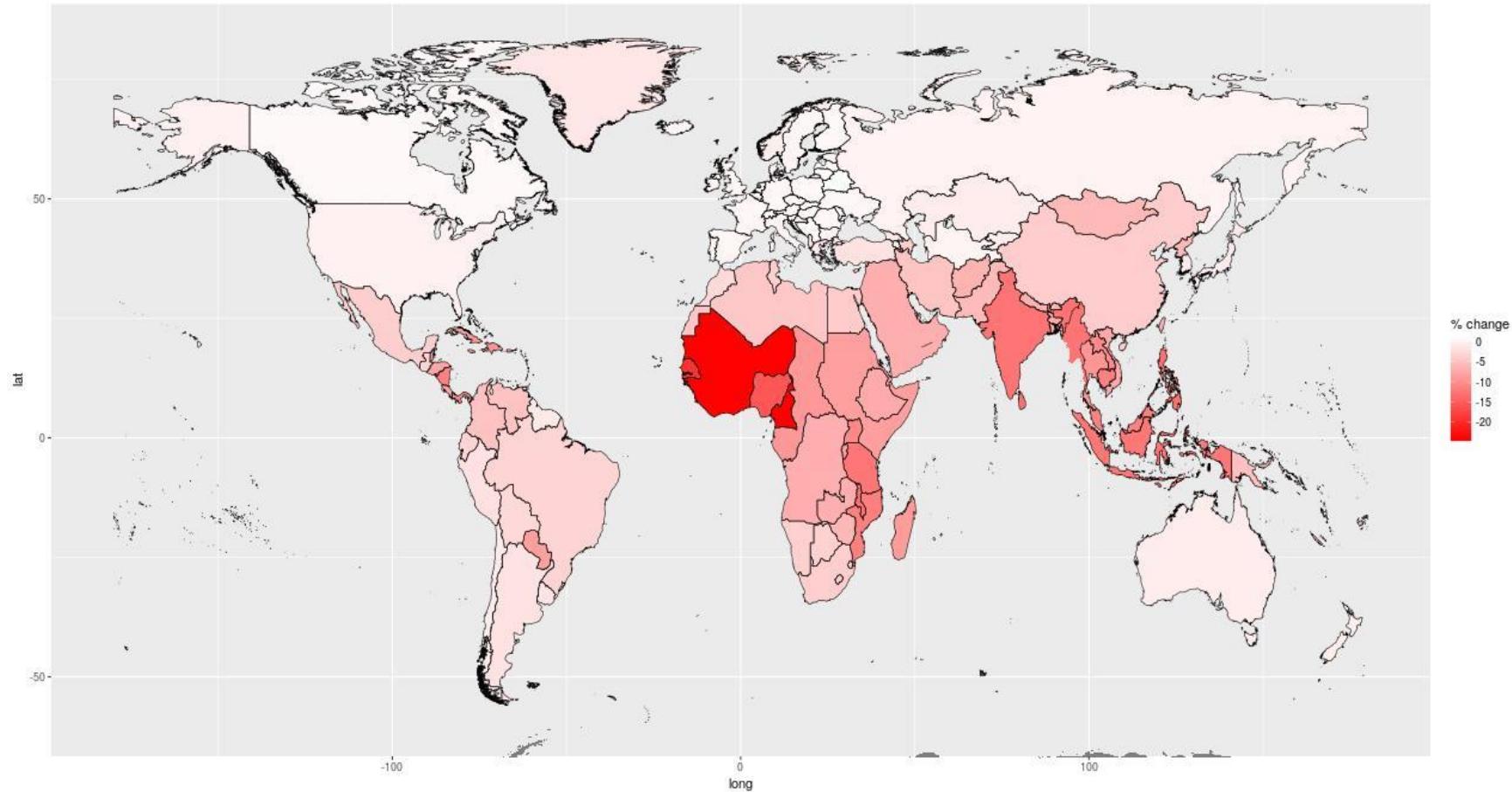- Implications for food security and trade patterns

Maize
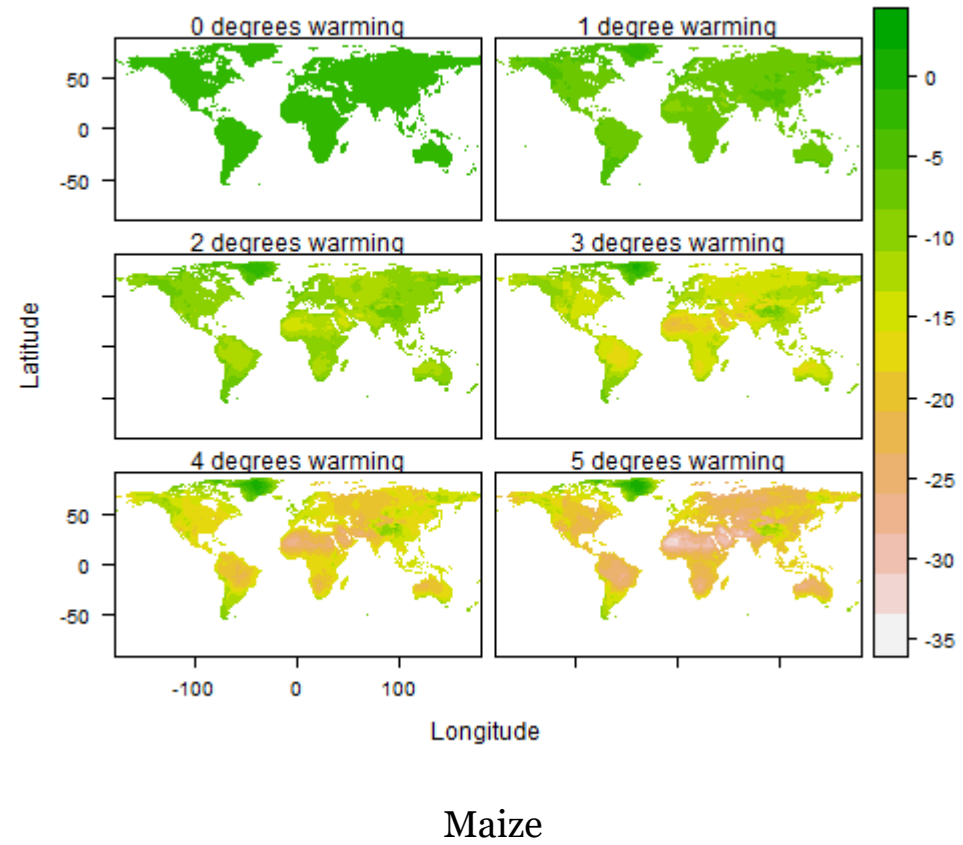
Global economic damages

Long run percentage losses in annual GDP globally: 1% to 28% depending on country; average loss in GDP *across* countries is 7%. RCP8.5, GDP losses by 2100 relative to 2015.

Earth's Future (2018), Nature Climate Change (2021)

Challenges… and opportunities

- Future precipitation patterns

- Extremes and variability

- Rapid onset hazards e.g. floods, storm surges, bushfires

- Labour productivity, sea level rise

- Integrating pest and climate (multi-hazard) damages on crops

Summary

- Damage functions can be used to predict consequences when and where data are scarce

- Generally this involves benefit transfer techniques to aggregate data, fit a model, and predict across time/space, though detailed methods may vary (e.g. meta-analysis, expert elicitation)

- We have used this approach to estimate asset damages from pests and diseases and crop damages from climate change

- Next steps to integrate climate and pest damages, and better understand damages from extremes