Future climate trends What we know and don't know and implications for adaptation of crop production

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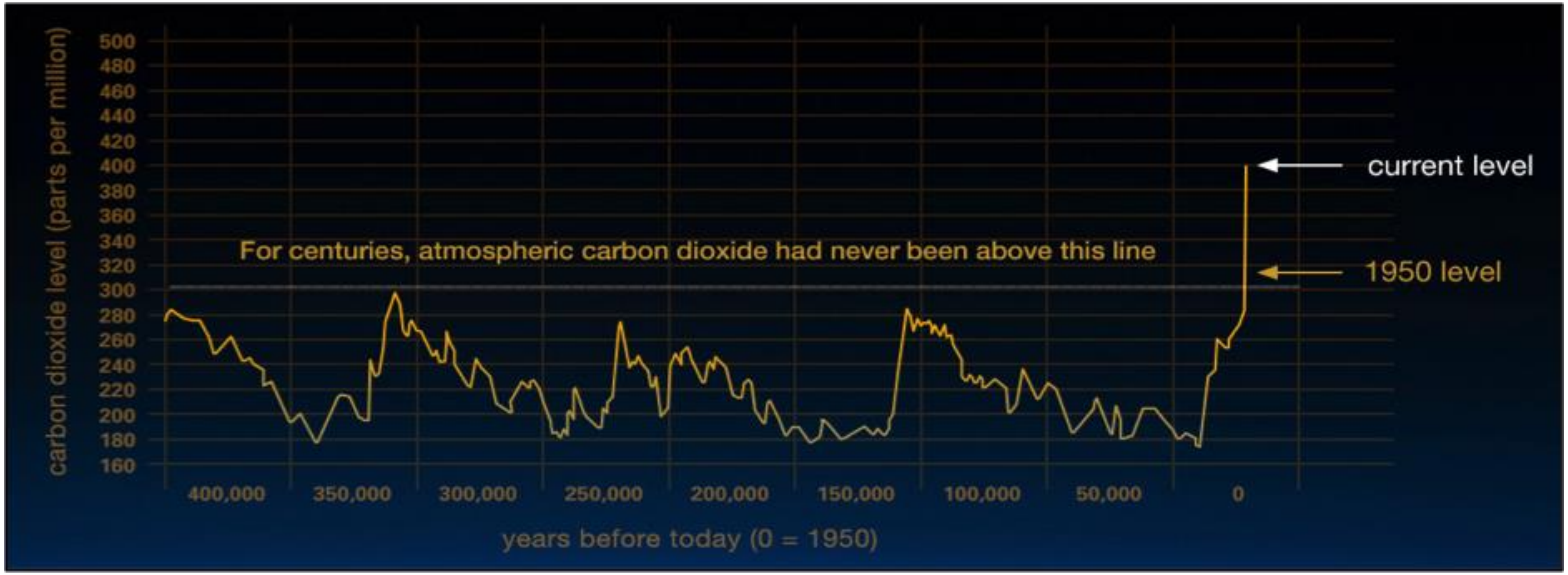
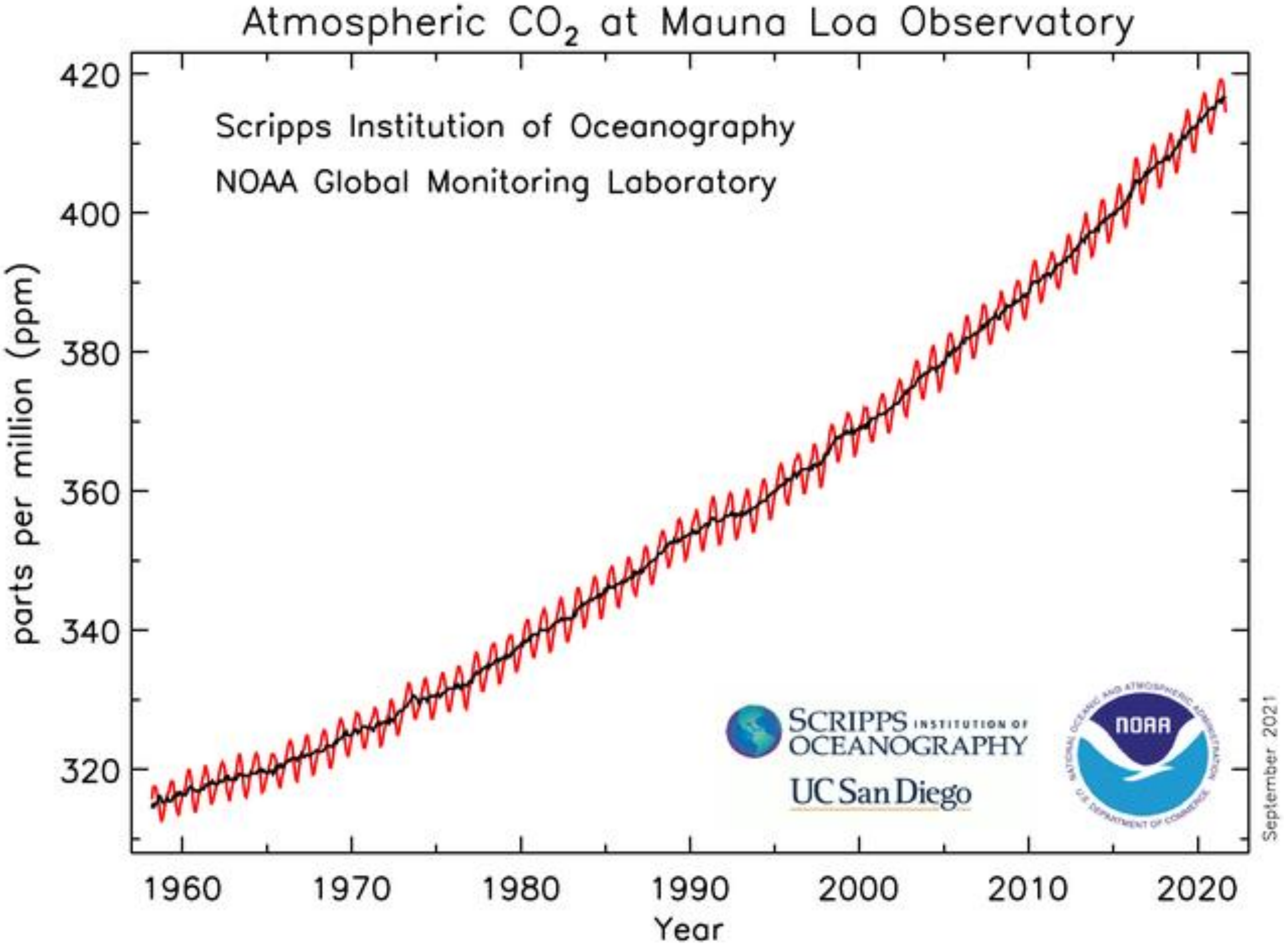


The present situation

Global temperature have increased by 1.1 ^{o}C (IPCC report 2021), more so on land surfaces

Climate change has become a reality



Atmospheric CO_2 at Mauna Loa Observatory
Scripps Institution of Oceanography
NOAA Global Monitoring Laboratory
parts per million (ppm)
420
400
380
360
340
320
1960
1970
1980
1990
2000
2010
2020
Year
SCRIPPS INSTITUTION OF OCEANOGRAPHY
UC San Diego
NOAA
September 2021

Looking into the future…

Most of the anticipated climate change and the impacts thereof is still ahead of us

Impact of climate change on future crop production

Climate change has a direct impact on agriculture by affecting the climatic conditions:

- Temperature (higher average, higher variability and more extreme events)
- Rainfall (changing average, higher variability, more extreme events)
- CO_2 levels increased
- More frequent extreme weather events
- Possibly other climatic factors change such as radiation, relative humidity, etc.
- Climatic factors influence crop growth and livestock performance directly, for instance through heat stress in crops and animals, and also indirectly, for instance a changing climate has an impact of the pressure of pests and diseases, on soil processes, and so forth

Predicting the future climate

Highly complex models simulating the global climate system, referred to as Global Circulation Models or GCMs, are typically used to predict the future climate (over decades) for a certain greenhouse gas emission scenario

Predictions by GCMs are downscaled to predict climate weather patterns at a given site

GCM predictions come with uncertainties

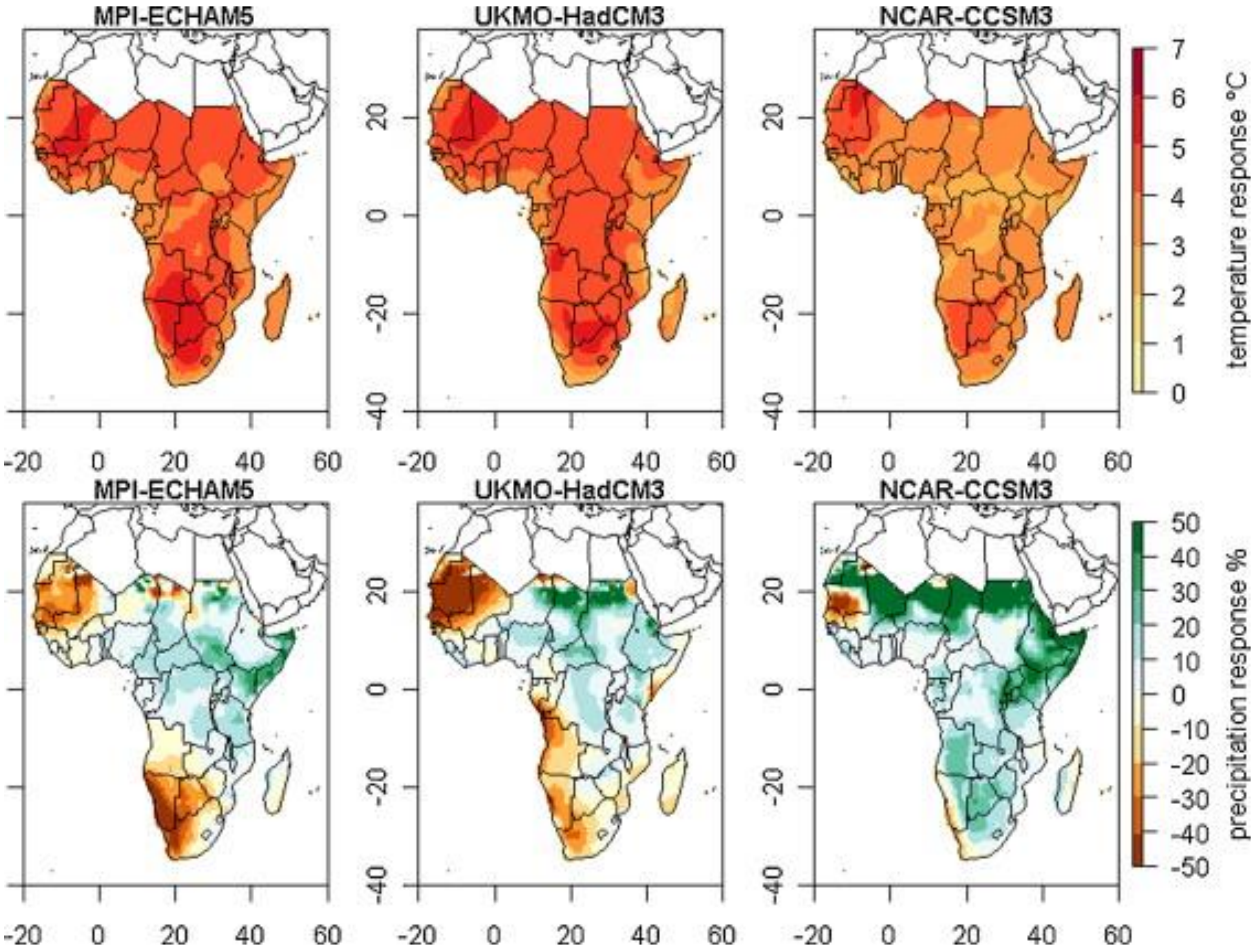
- Different GCMs give different predictions for a given emission scenario
- Different downscalings derived from the same GCM can give different predictions

In general, GCMs are reasonably accurate at predicting future temperatures

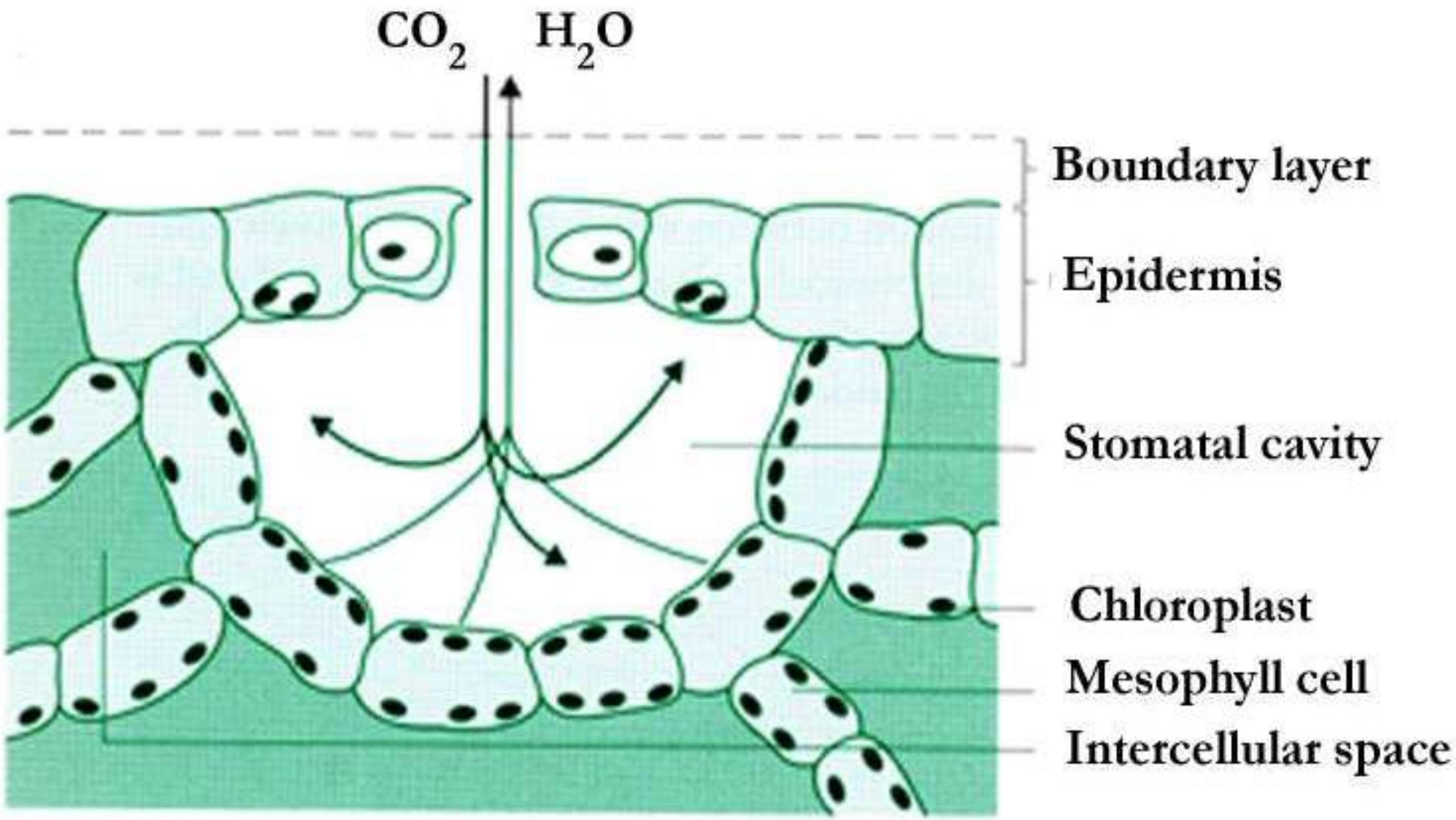
GCMs are not accurate for predicting future rainfall

GCMs are not good at predicting the occurrence of extreme weather events.

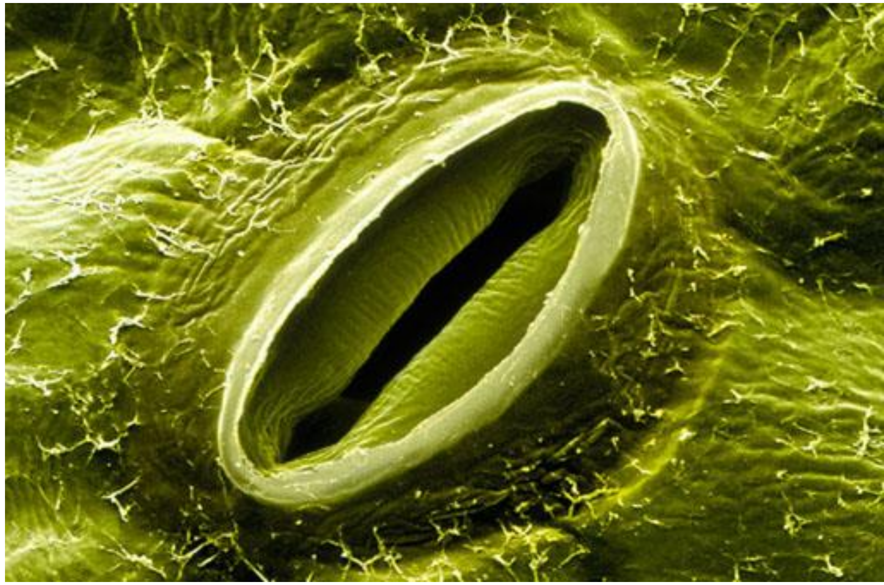
Temperature and precipitation changes predicted for the end of this century by different GCM downscalings



Elevated ambient CO_2 [eCO_2] has a large, often neglected impact on crop performance



Stomatal cavity of a plant



General impact of [eCO_2] on crop growth

[eCO_2] reduces the stomatal conductance

[eCO_2] may increase the photosynthesis rate by improving the radiation use efficiency

[eCO_2] may reduce transpiration rate of the crop

[eCO_2] may increase crop canopy temperatures due to reduced transpirational cooling

The different mechanisms interact with each other, for example:

- Higher photosynthesis rate due to [eCO_2] may lead to a larger leaf area increasing transpiration
- Reduced transpiration due to [eCO_2] leading to increased crop temperatures may increase heat stress, reducing photosynthesis rate

The impacts of [eCO_2] interact with other growth factors, for example:

- Nitrogen stress in crops reduces the positive impacts of [eCO_2] on photosynthesis
- Mild water stress may increase the impact of [eCO_2] on photosynthesis, severe water stress may annihilate the benefits of [eCO_2]

How to measure impacts of future [eCO_2] on crop performance?

Closed climate chamber / greenhouses

Open Top Chambers (OTCs)

Free Air CO_2 Enrichment (FACE) experiments

Impact of [eCO_2] on crop evapotranspiration and yield

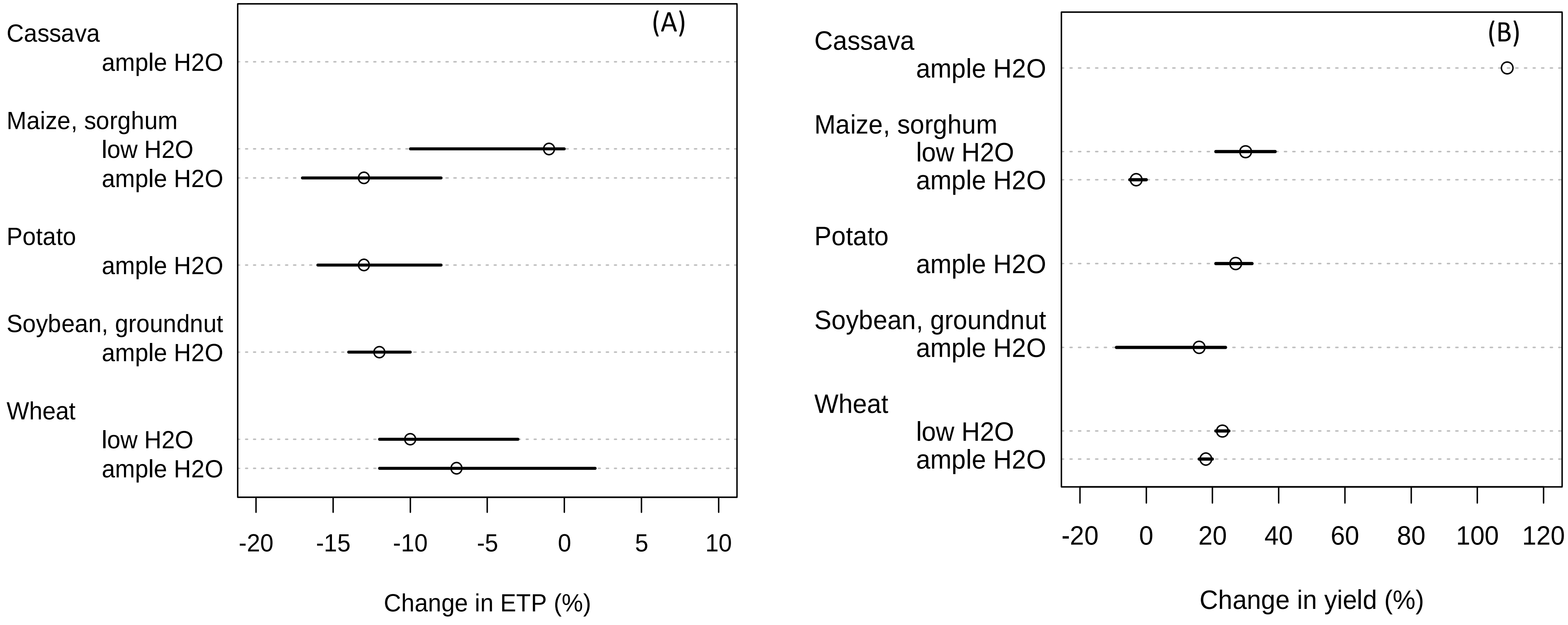


Figure 1. Responses of (A) evapotranspiration (ETP) and (B) agricultural yield to eCO_2 (adjusted to 550 ppm) for optimal conditions and situations with water stress, average responses and ranges. Source: Kimball (2016).

Methodological considerations when assessing [eCO_2] impacts

- [eCO_2] experiments with crops are expensive and technically challenging
- A comparison of results from FACE and OTC experiments suggests that the impacts of [eCO_2] measured in FACE experiments should be corrected with a factor 1.5. So the impacts of [eCO_2] on crop performance may be even much stronger. Fluctuating [CO_2] levels in FACE experiments are likely to disturb plant performance
- [eCO_2] experiments are mostly carried out in temperate regions (a geographic bias), data from biomes representative for southern Africa, i.e. (sub-)tropical and high-altitude regions, are largely lacking
- [eCO_2] experiments are typically carried out in low-stress environments, while high-stress production environments (i.e. with heat stress, drought stress, nutrient stress, biotic stresses) prevail in southern Africa

Impacts of warmer temperatures

Faster crop development, maturation and senescence, and therefore shorter growing periods.

More rapid accumulation of heat units during the active growing stages, less cold units (e.g. for fruit trees in winter)

Temperature affects radiation use efficiency of the crop and thereby photosynthesis rate and growth in many respects.

Increased heat stress in crops, reduced cold stress. Less risk of frost damage in crops

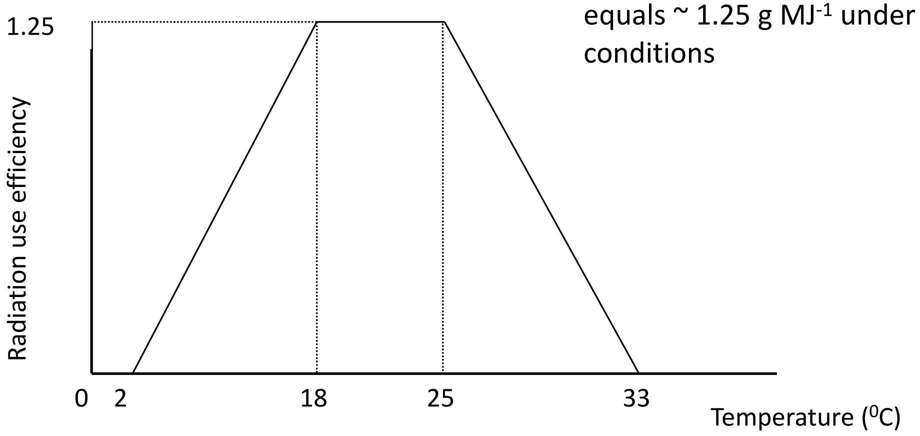
Heat stress during sensitive stages of a crop can be very damaging to yield, in other stages the crop can easily recover

Higher evapotranspiration rates and reduced water availability (neglecting any possible impacts of higher ambient CO_2 levels on water use by the crop)

Changing growing seasons, for instance earlier planting in spring

Many possible indirect effects, for instance:

Increases in biotic pressures in crops



Radiation use efficiency of potato equals ~ 1.25 g MJ^{-1} under optimal conditions

Changing rainfall patterns and a higher rainfall variability

We can not predict well if total precipitation will get more or less in future, but there is a high likelihood that rain distribution will become more variable (that is more intense showers and prolonged drought periods in between)

More intense rainfall showers generally reduces the effectiveness of rain (i.e. less water entering the soil profile, more water running off)

Increased risks of water logging and yield losses due to heavy rainfall

Increased risks of prolonged drought periods for crops and pastures leading to yield losses.

More unpredictable start and end dates of the suitable growing period as determined by water availability

Two main approaches to assessing the future impact of climate change on crop performance

1. Empirical methods: use relations between weather conditions and crop performance based on observations from the past to predict the future

2. Crop models: use mechanistic models simulating crop growth as affected by weather conditions to predict future yields

- Both approaches require a prediction of the future climate, typically based on GCMs. How correct are these predictions?
- Empirical methods assume that relationships from the past hold for the future. Is that true?
- Mechanistic crop growth models are hindered by our limited understanding of how environmental conditions affect crop growth and how this can be captured in mathematical equations. These models have been built to simulate yield under optimal growing conditions. They are not accurate at simulating the impact of nutrient and biotic stresses on crops.

Overview of results from studies predicting future maize yield under climate change in southern Africa

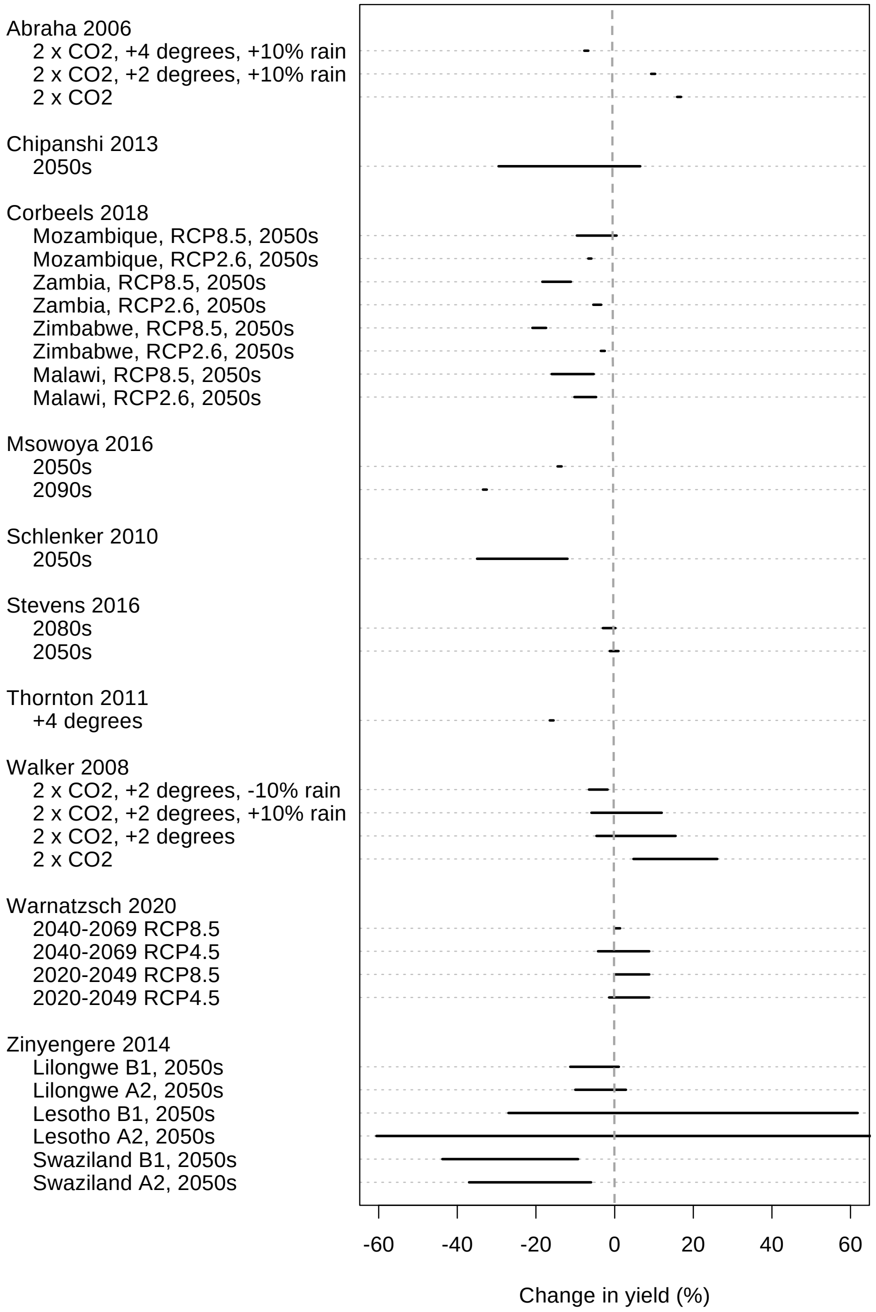


Figure 2. Predicted impact of climate change on maize yields in southern Africa

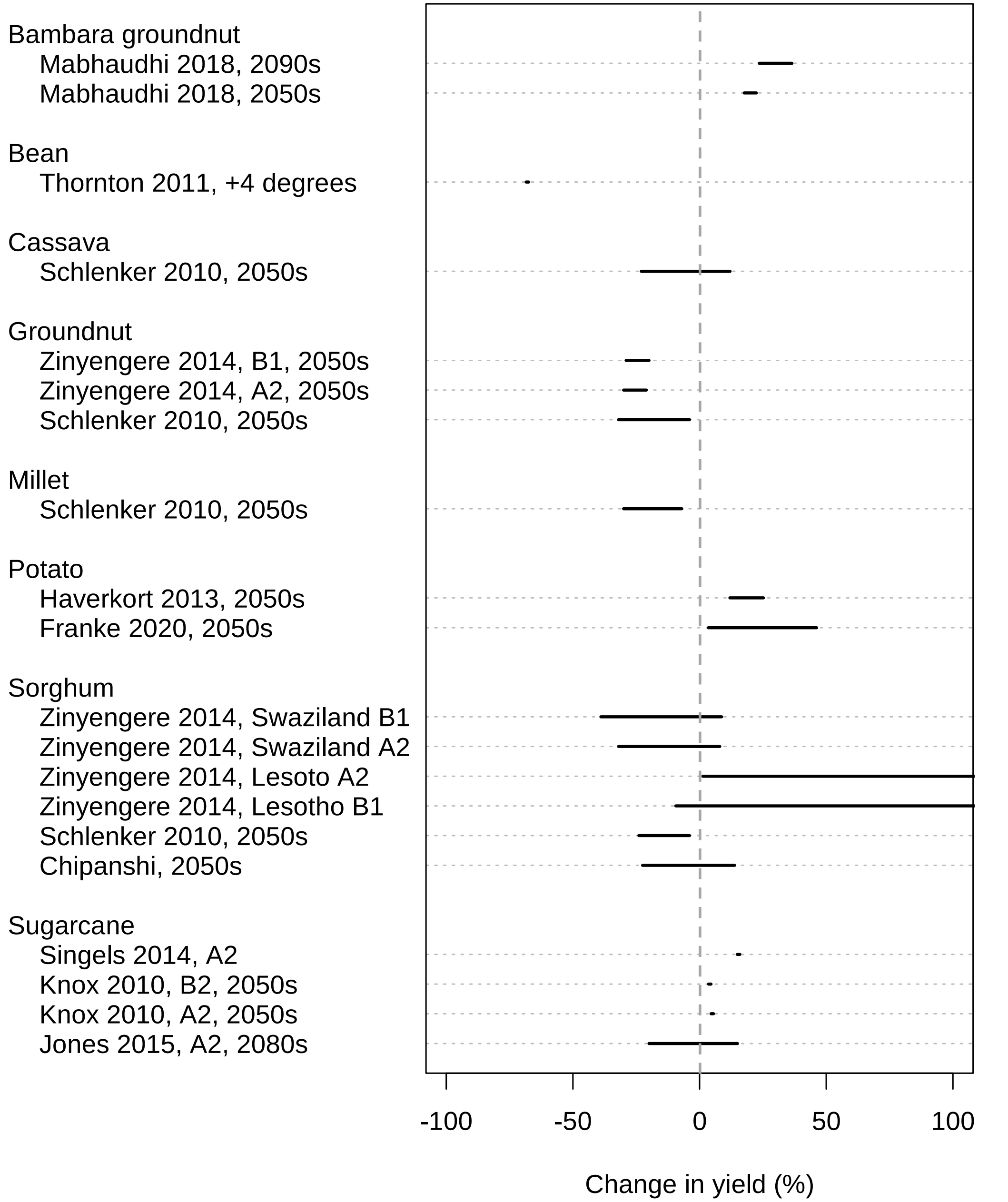


Figure 3. Predicted impact of climate change on yields of crops other than maize in southern Africa

Future impact of climate change on sugarcane

- Sugarcane can stand warm temperatures and in most cases, sugarcane farmers will likely get away with increased mean temperatures
- As a C_4 crop, sugarcane is likely to give increased yields under [eCO_2] only when water availability is limiting
- Sugarcane is likely to become more efficient with the available water under [eCO_2]
- Extreme weather events (storms, droughts, heavy rainfall, …) are likely to increasingly impact sugarcane production
- Water storage (at field, farm or dams at district level) is likely going to be key in the adaptation to climate change

Concluding remarks: dealing with uncertainty

There are lots of uncertainties around the prediction of future impact of climate change on crop production.
This large variability is caused by:

1. Uncertainty surrounding future weather predictions
2. Uncertainty around the parameterisation and structure of crop models

The uncertainties are so large that some question the usefulness of using models to predict future yields; rather focus on farmers' current adaptations and ways of dealing with climate change and variability

It is difficult to communicate uncertainty around climate change predictions and the impacts of thereof to the general public.

Despite many uncertainties around climate change and its impacts, it is beyond doubt that anthropogenic climate change is real and the impacts on agriculture and other sectors will be dramatic.

Anticipation is key! Adaptation to climate change is a slow process. Most of the expected change in climate and the impacts thereof on agriculture is ahead of us.