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Use and misuse of modelling for projections of climate change impacts on crops and pastures

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Outline

- Climate change and food supply
- Uncertainties in projections of impacts
- Modelling crops under elevated CO_2
- Extreme climate events
- Biotic interactions
- Perspectives

Whatis climatechange?

Increasein the main greenhouse gases

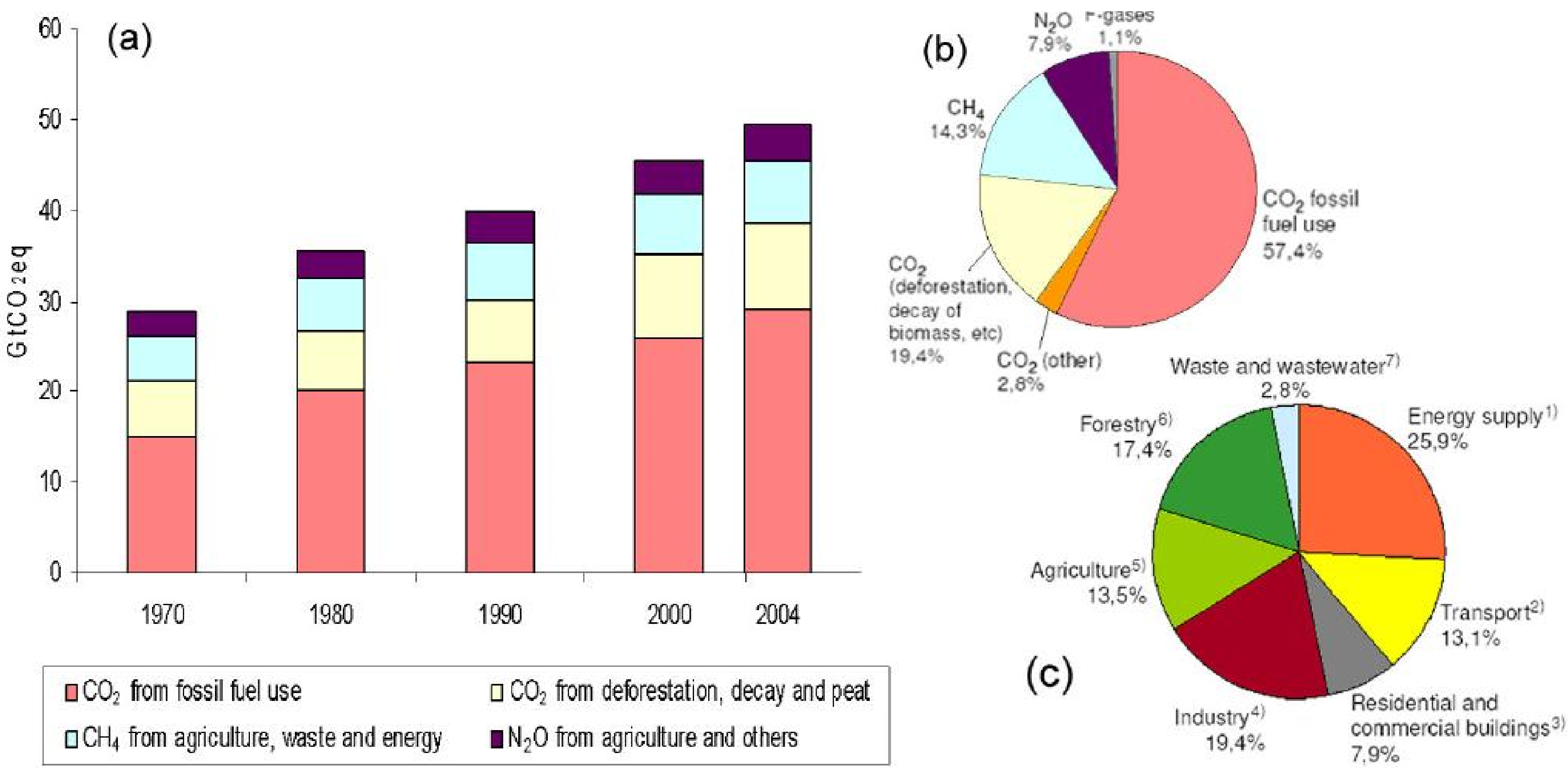
- Carbondioxide (CO_2)
- Methane(CH_4)
- Nitrousoxide (N_2O)

Changes in climate

- Temperature
- Precipitation
- Extreme events

Over the coming decades and centuries

Global increase in anthropogenic greenhouse gas emissions

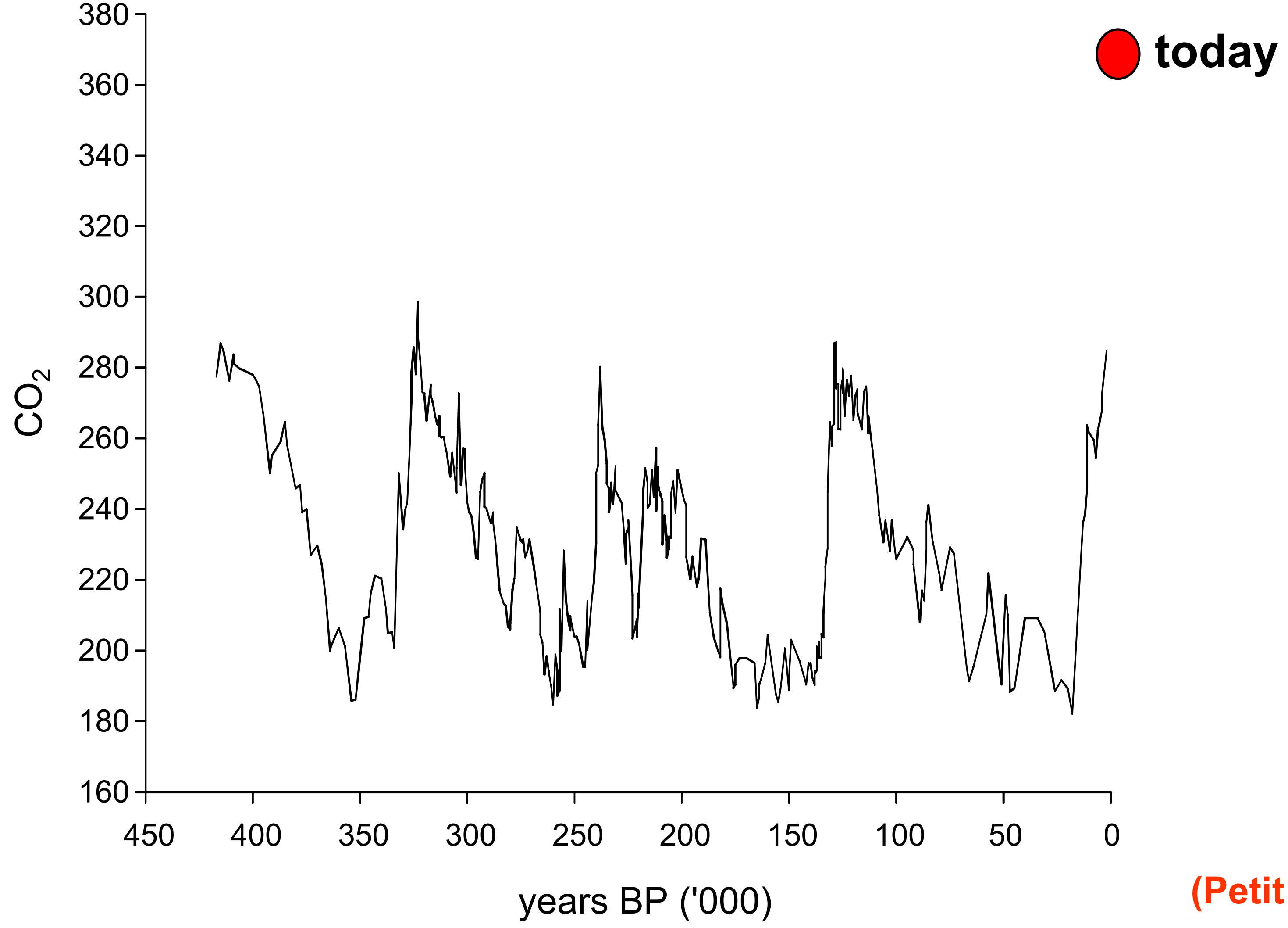


IPCC 2007

Global greenhouse gas emissions covered by the Kyoto protocol have increased by 70 % from 1970 to 2004

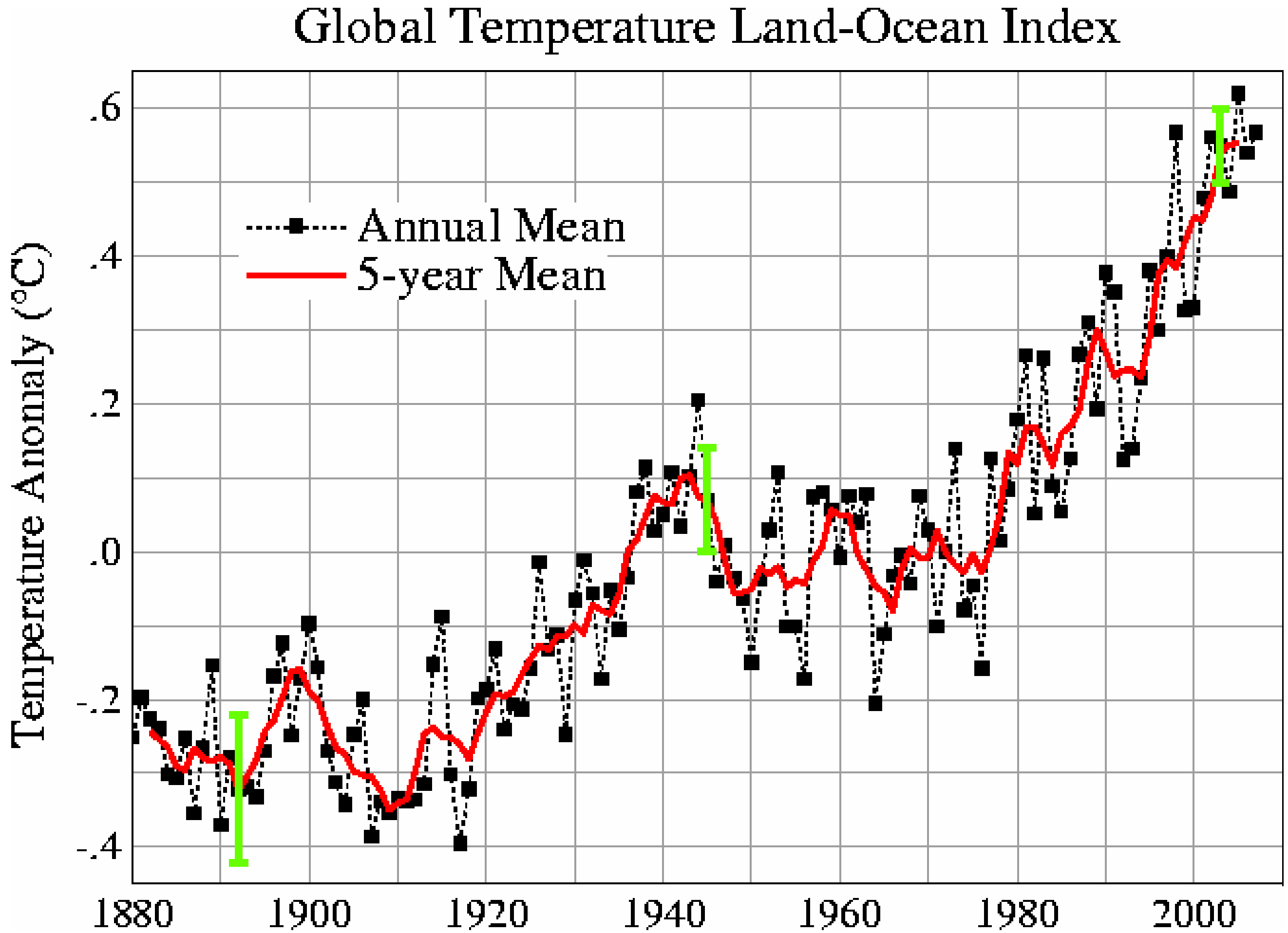
Atmospheric CO_2 in the past

Thelast 400 ‘000 years



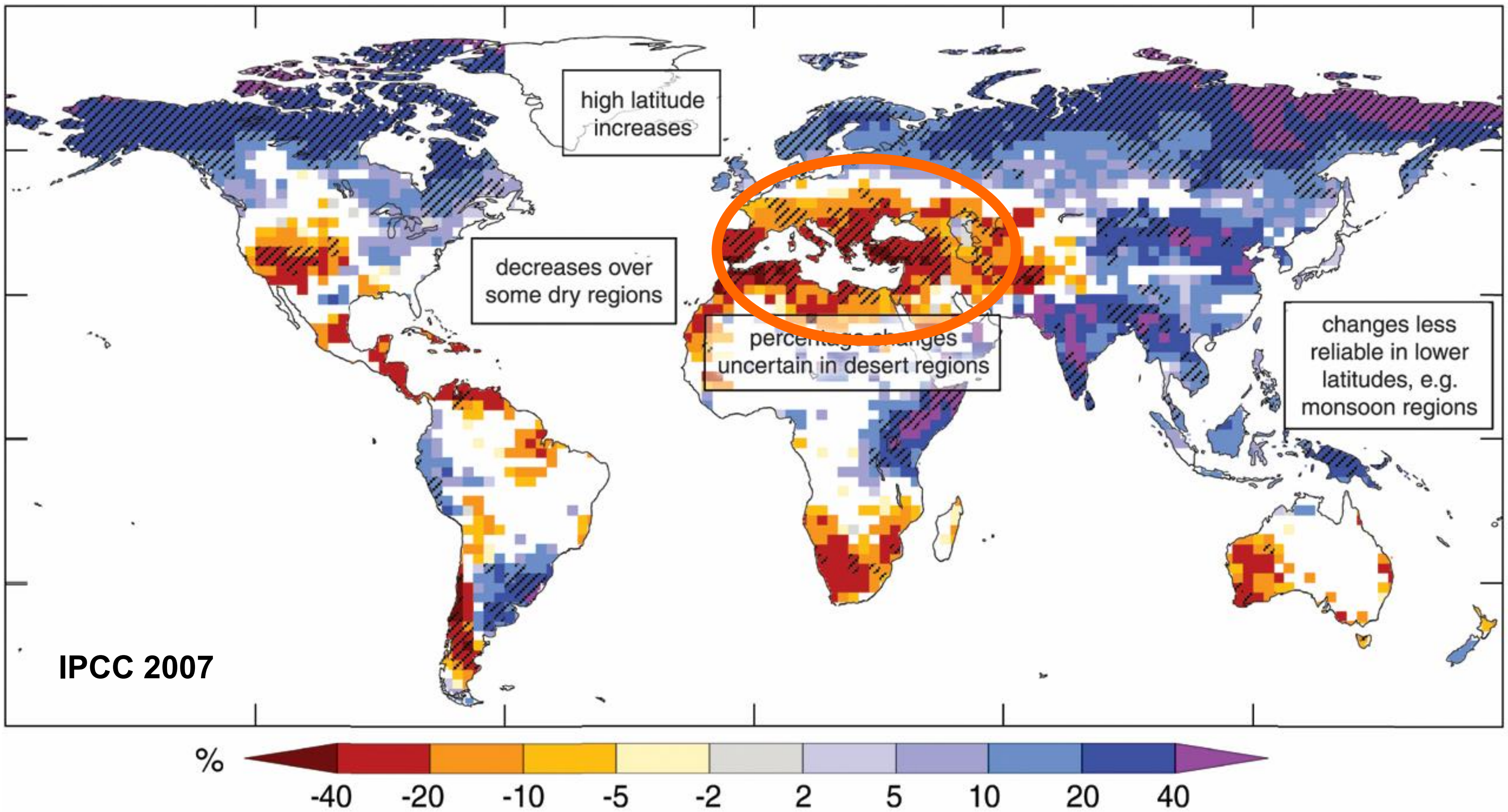
(Petit *et al.*, 1999)

Global warmingsince1880



(NASA, 2008)

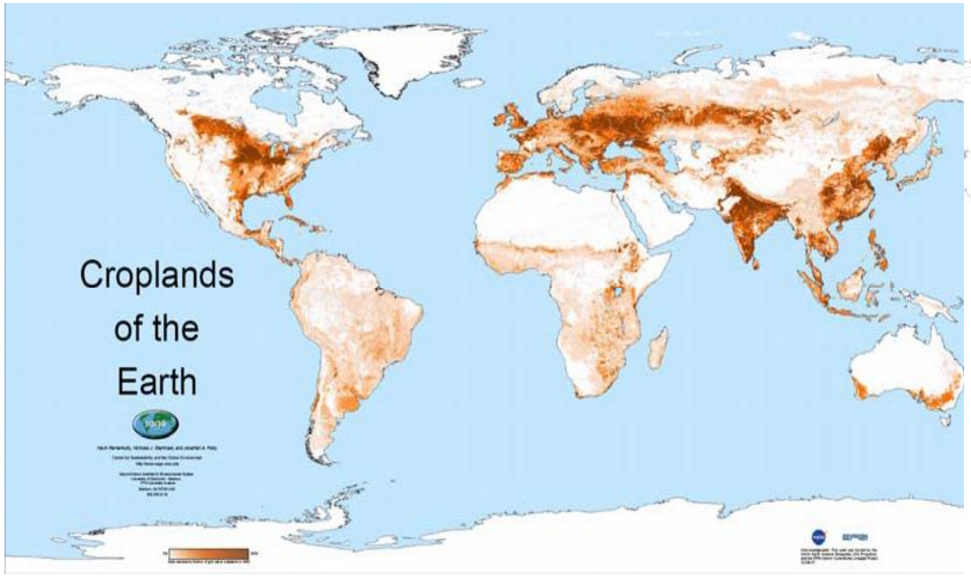
Projected changes in annual water runoff



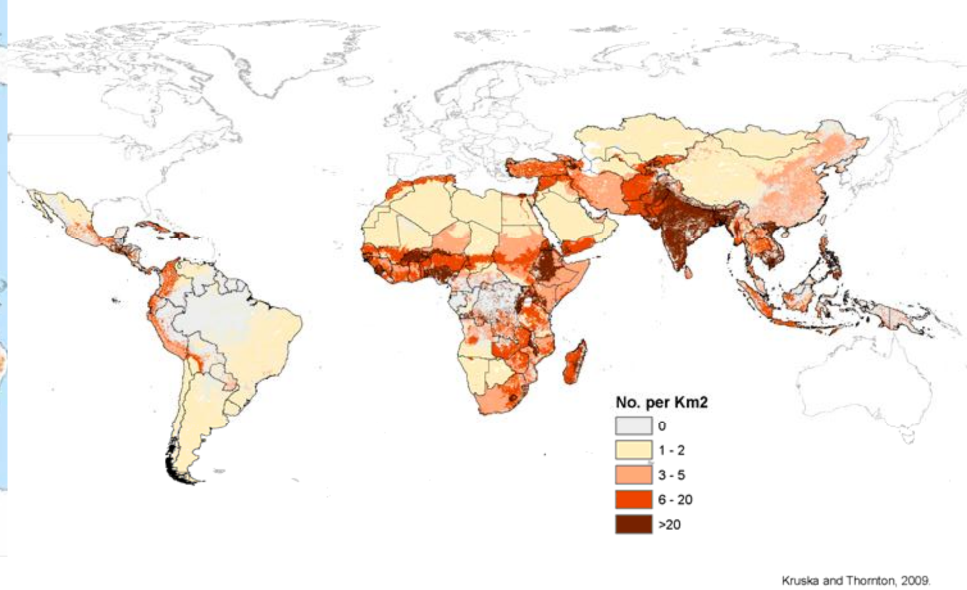
Frequency of severe summer droughts is likely to double over South Europe (Lehner et al., 2006)

The global food supply challenge

Crops cover ~ **1.5 billion ha, 10%** of global ice-free land;
Pastures add another **2.5 billion ha; or 20%**



Density of Poor Livestock Keepers

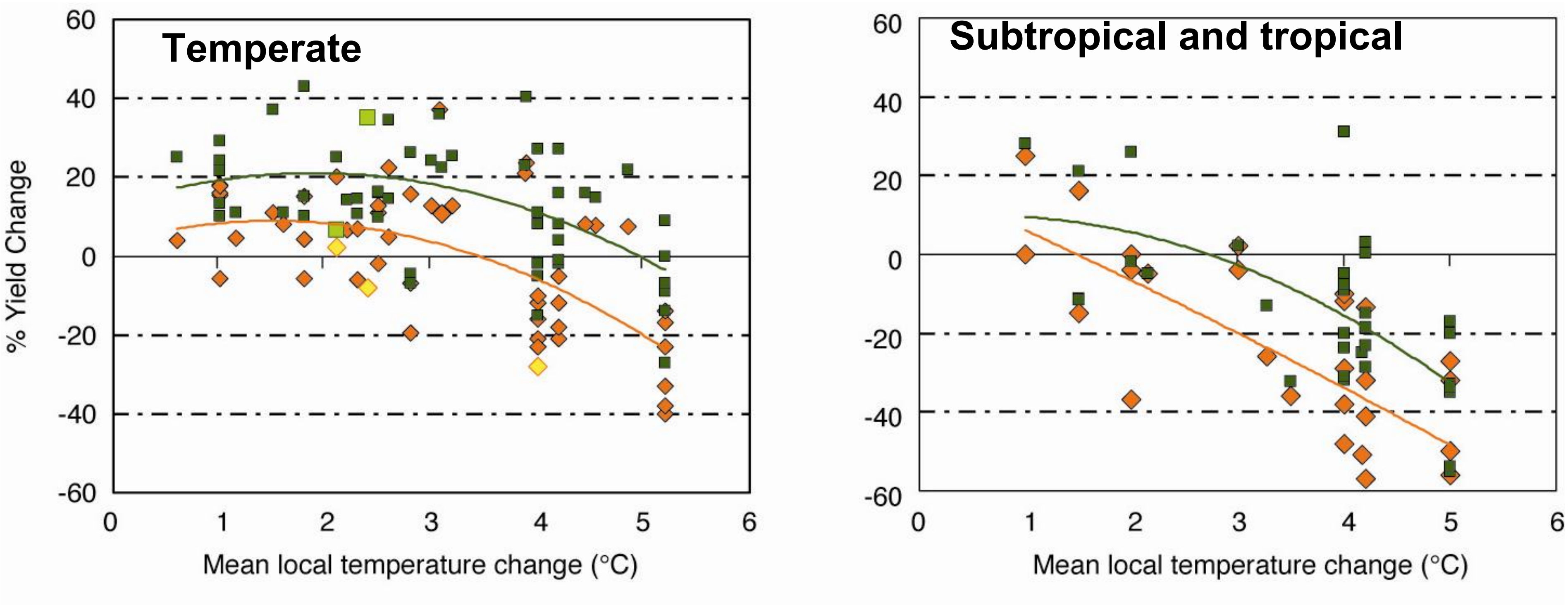


The number of undernourished people has reached **1 billion** for the first time ever (FAO, 2009)

Existing projections indicate that future population and economic growth will require a **doubling of current food production**:

Increase from 2 to 4 billion tons of grains annually.

Modelled climate change impactson wheat yields: with or without adaptation

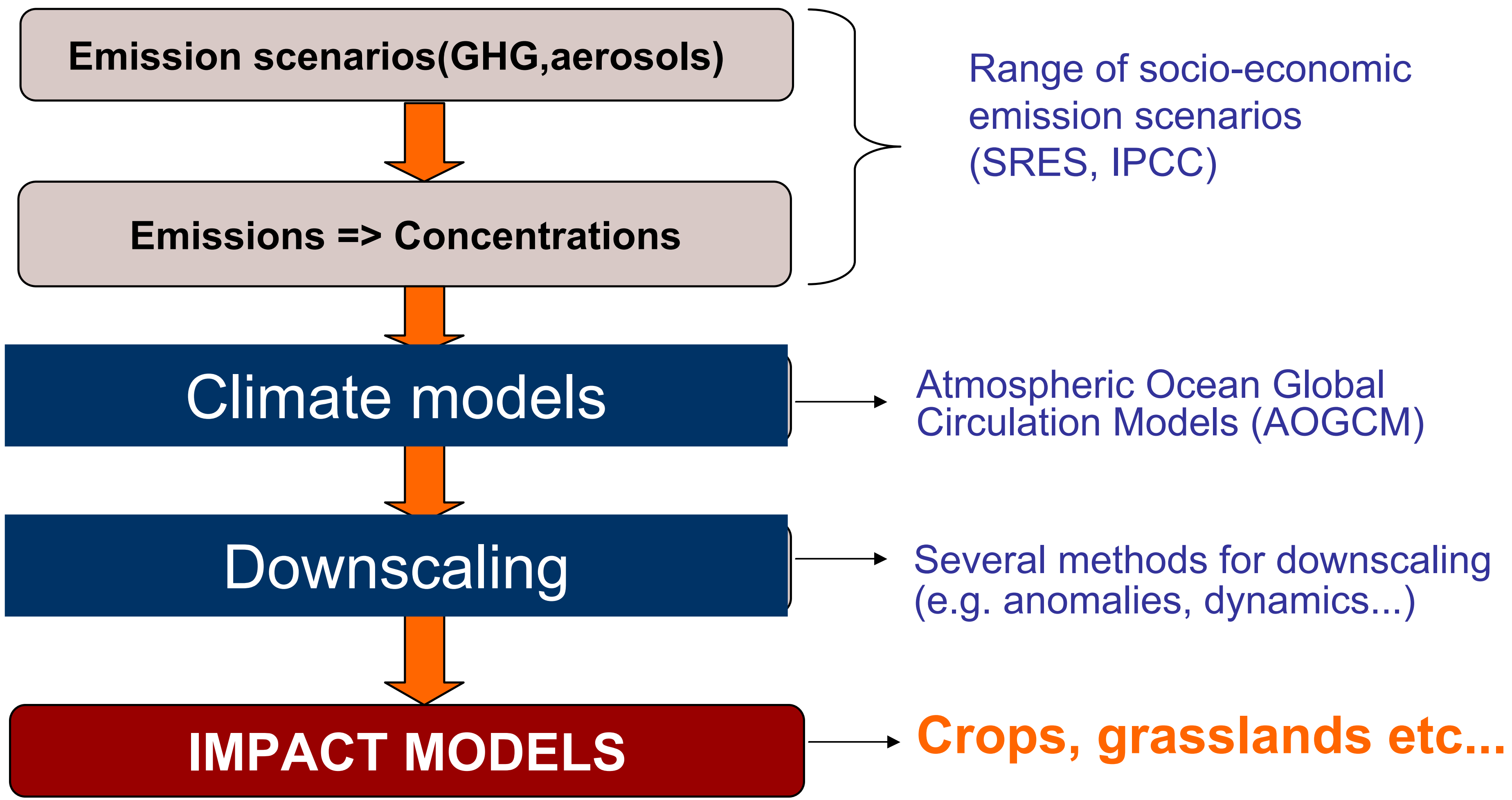


Increased frequency of heat stress, droughts, and floods negatively affect crop yields and livestock beyond the impacts of mean climate change, **creating the possibility for surprises, with impacts that are larger, and occurring earlier**, than predicted using changes in mean variables alone.

(IPCC,2007)

1°Uncertainties in climate change projections for crops and pastures

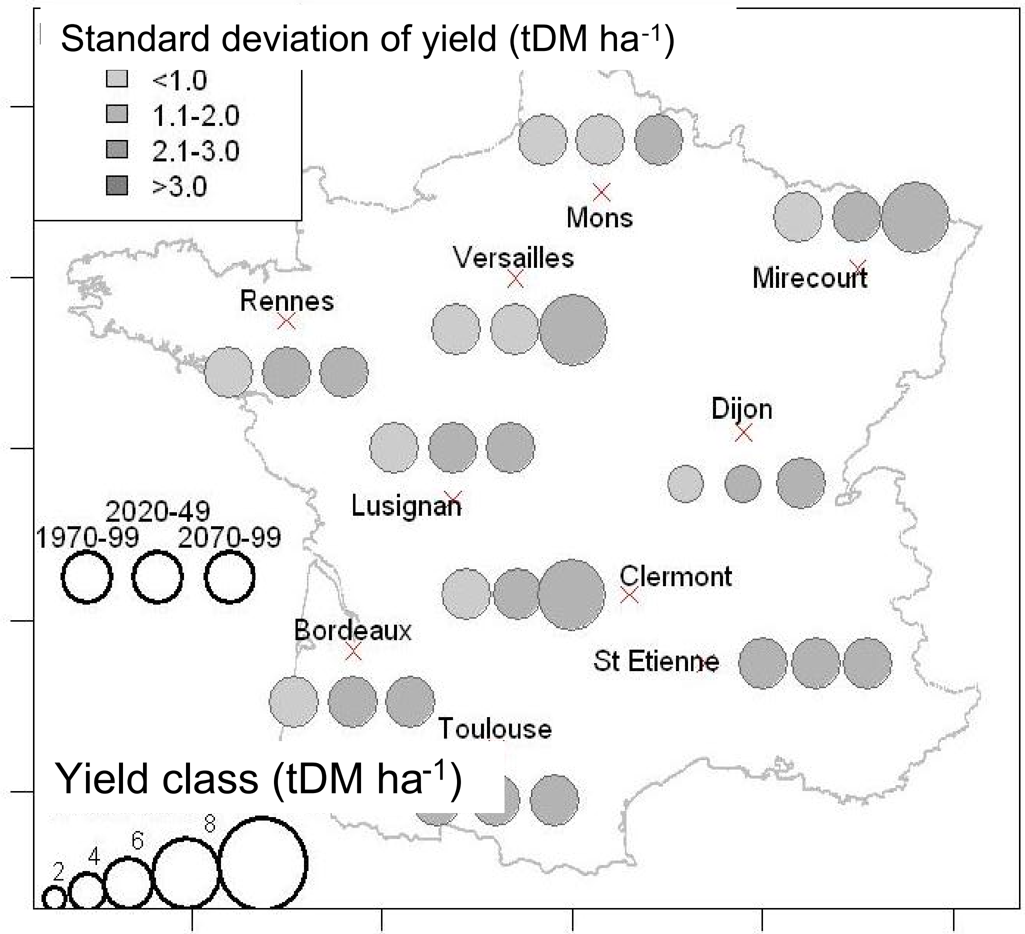
From GHG emissions to climate change impacts



Crop & grassland models classification

Empiric	Functional	Mechanistic
Usually obtained from regressions between yields and local meteorological variables.	Based on laws and empirical relationships.	Based on the physical laws of the soil-water-plant-atmosphere continuum.
Valid only for the place and conditions where they were obtained.	Usable under many conditions, after local calibrations.	Theoretically valid to any meteorological, soil or crop conditions.
Few input data is required, generally available.	Standard information is required, available in many places.	Detailed input data is needed, generally not available.

Exemple of site based modelling: climate change impacts on forage DM yields in France

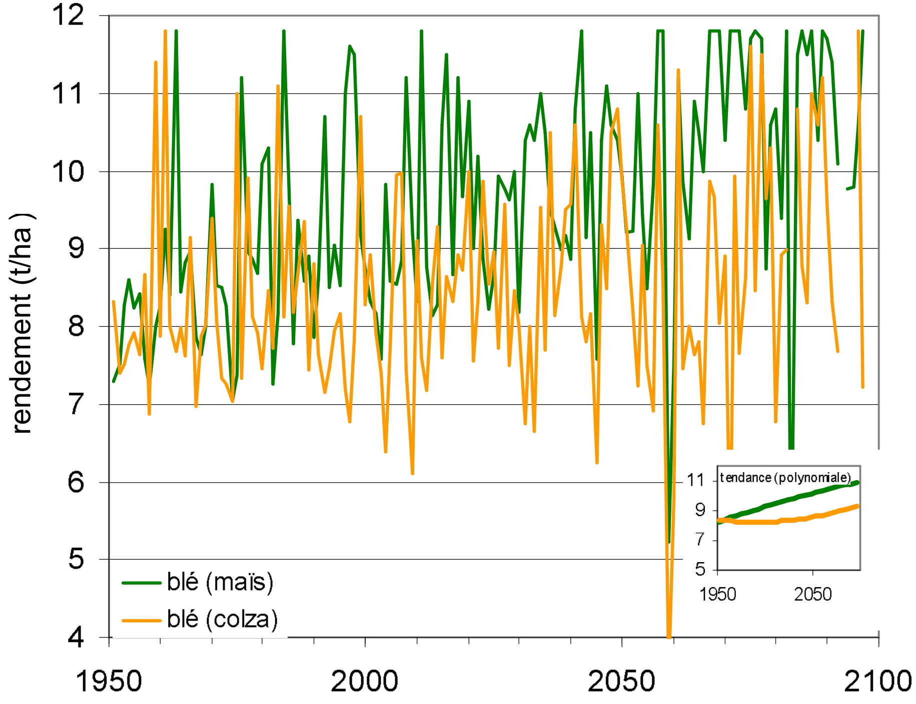


Mechanistic grassland model, PASIM;
Low emission scenario, A1B; climate model ARPEGE;
Downscaling by statistical disagregation, Boéet al., 2006;
Low input long-term grassland; shallow soil.

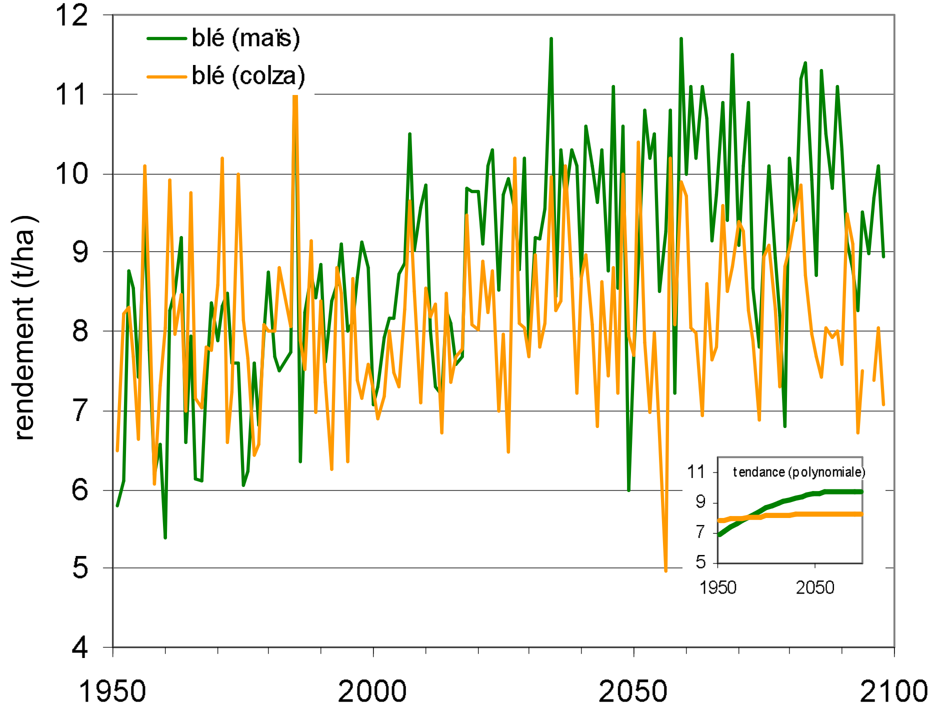
(Graux et al., in preparation)

Projected wheat yields with downscaled scenarios: increased variability over time of wheat yield (grown after maize or rapeseed)

- Toulouse



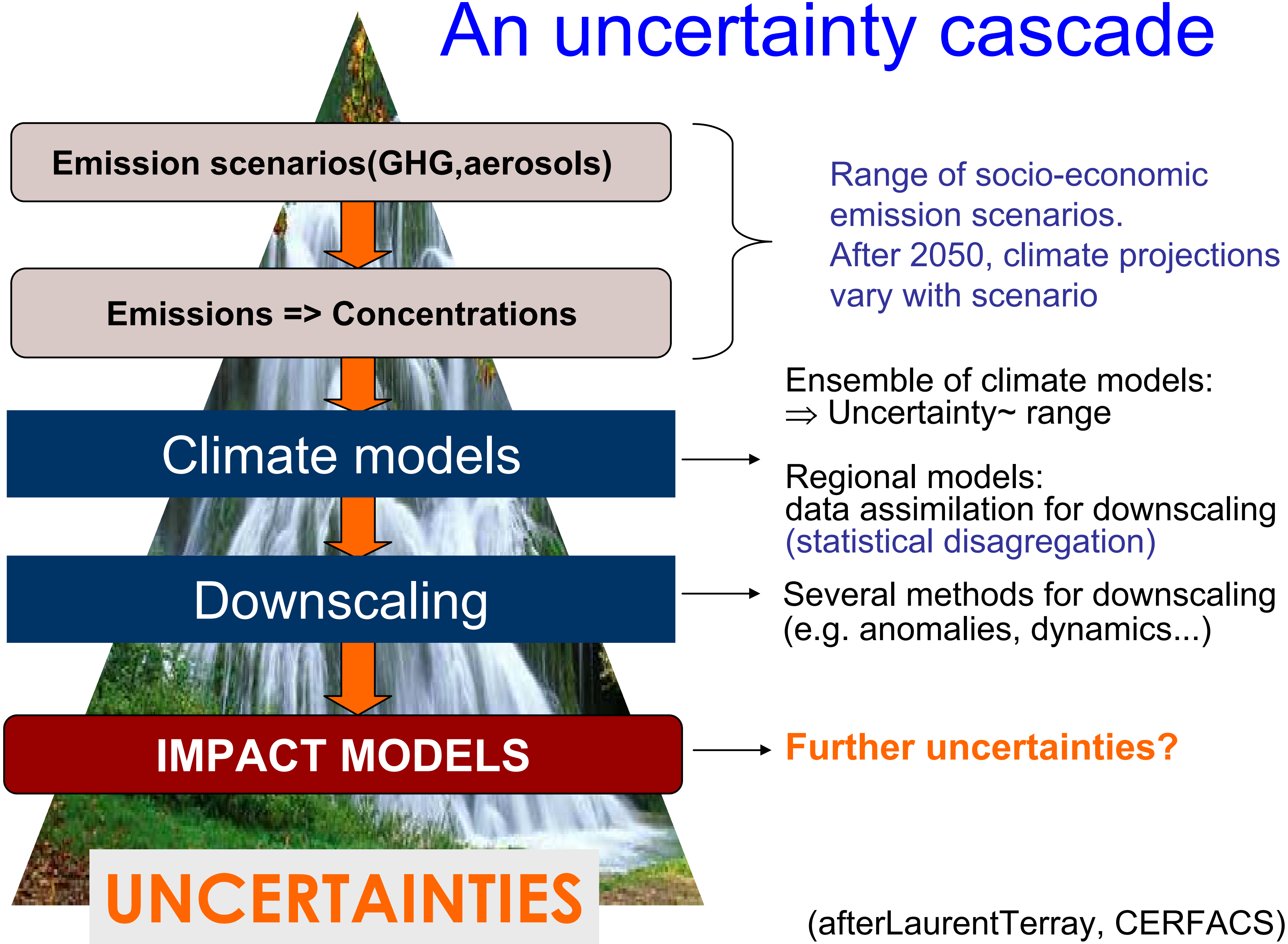
- Colmar



Increased interannual variation has a negative impact *per se*

(Brisson et al., in preparation)

An uncertainty cascade



(afterLaurentTerray, CERFACS)

Climate change signal compared to sources of variability & uncertainty

Variance decomposition analysis:
interannual variability is used to scale variance of other factors

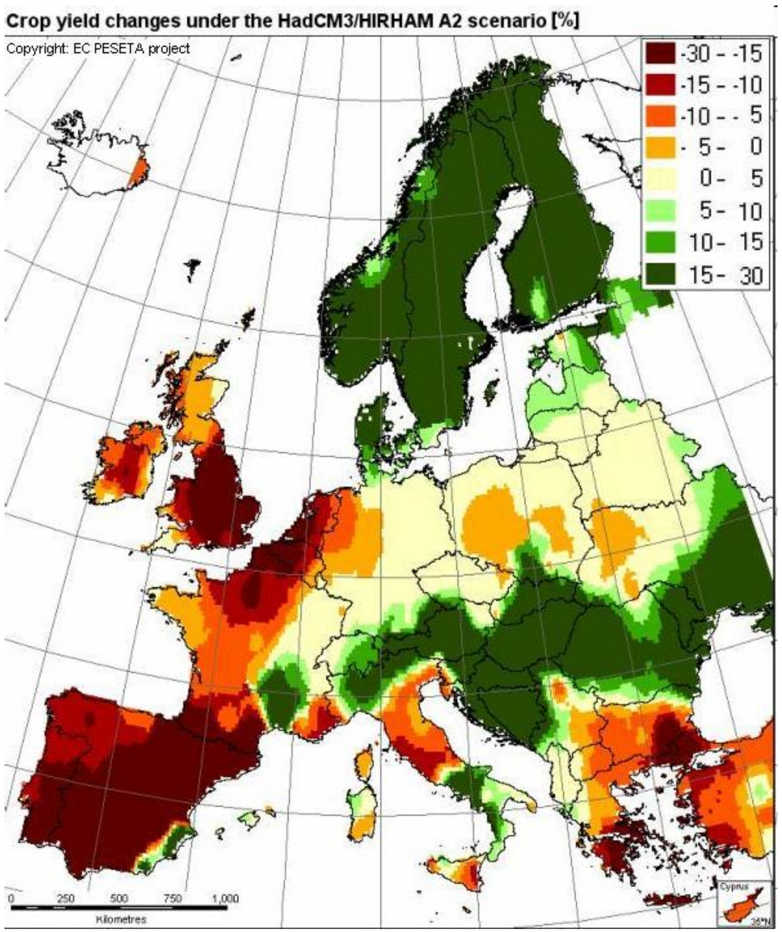
Factors	Weight (%)
Interannual variability	100.00
Management (intensive vs. extensive)	50.18
Climate change	6.03
SRES scenario	2.99
Downscaling method	2.61
GCM initialization	0.24

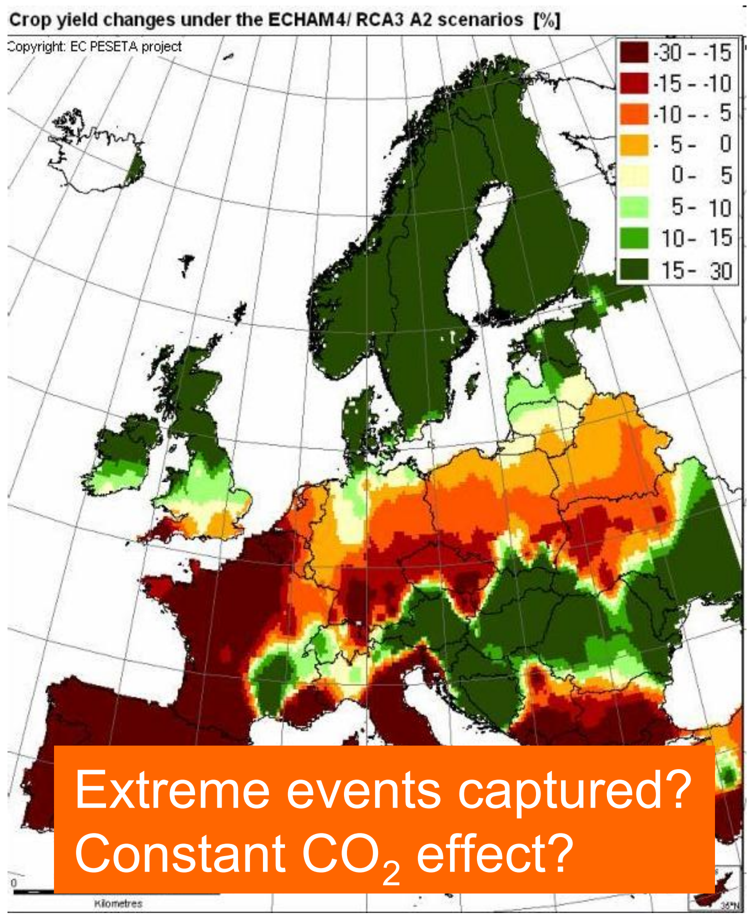
Forage DM yield simulated by PASIM mechanistic model
Comparing two managementsthree IPCC SRES scenarios, two initializations of ARPEGE GCM model, three downscaling methods and

(Graux et al., in preparation)

Upscaling : simulated crop yield changes (%) by 2080s relative to1961-1990

High emission scenario (IPCC A2), two climate models:
(left) HadCM3, (right) ECHAM4, DSSAT crop model (Jones et al., 2003)



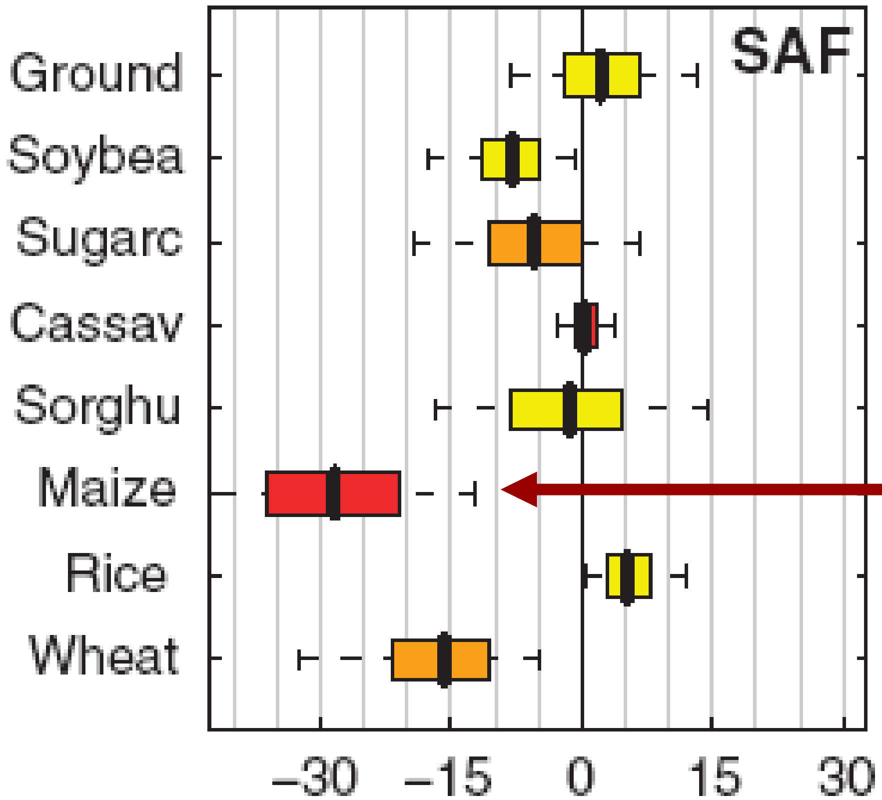


Map elaboration by EC JRC/IES. Livestock not considered

(EC PESETA project)

Modelling food insecurity by 2030

30% of farmers in developing countries are currently food-insecure



(Southern Africa region)

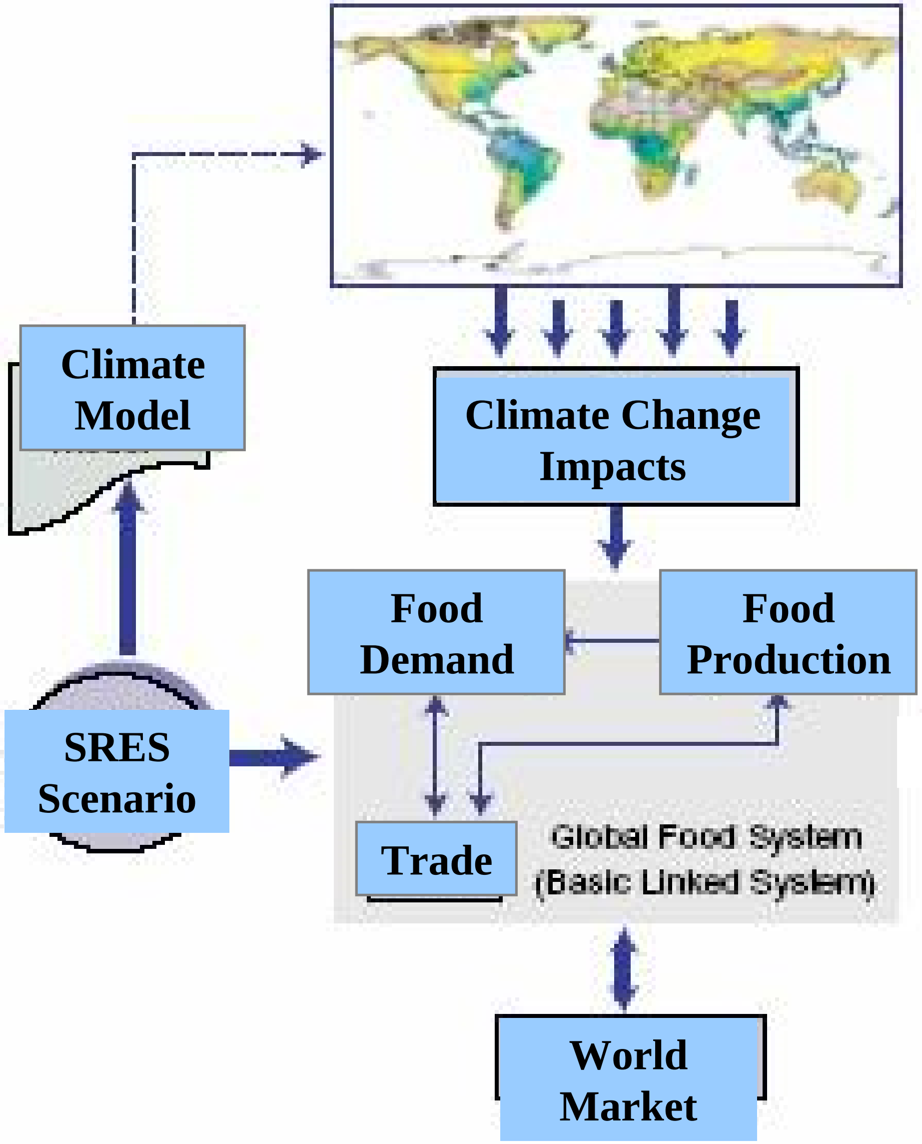
High food insecurity
Large reduction in yield
+ Major crop

Empirical model
No CO_2 effect?

Regional climate models ensemble, **statistical** approach of crop modelling
=> Climate change may decrease local yields while contributing to a global increase in commodity prices by 2030

(Lobell et al., 2008, Science)

Scaling agro-economics from site to region?



Global AgroEcological Zones

Issues: World trade tends to dominate over physiological processes;

Economic models ‘toostable ’

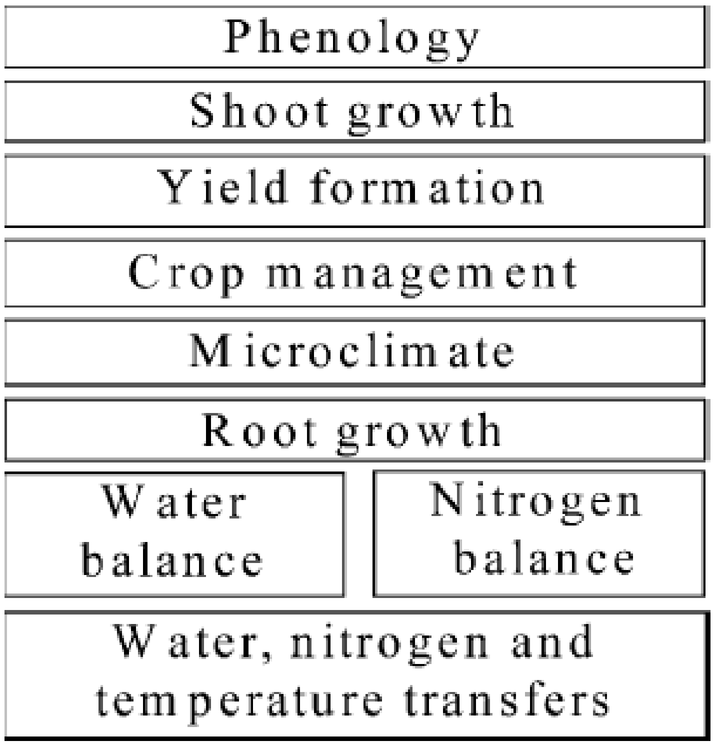
Socio-economic model

Validation?
Uncertainty?
Constant CO_2 effect?

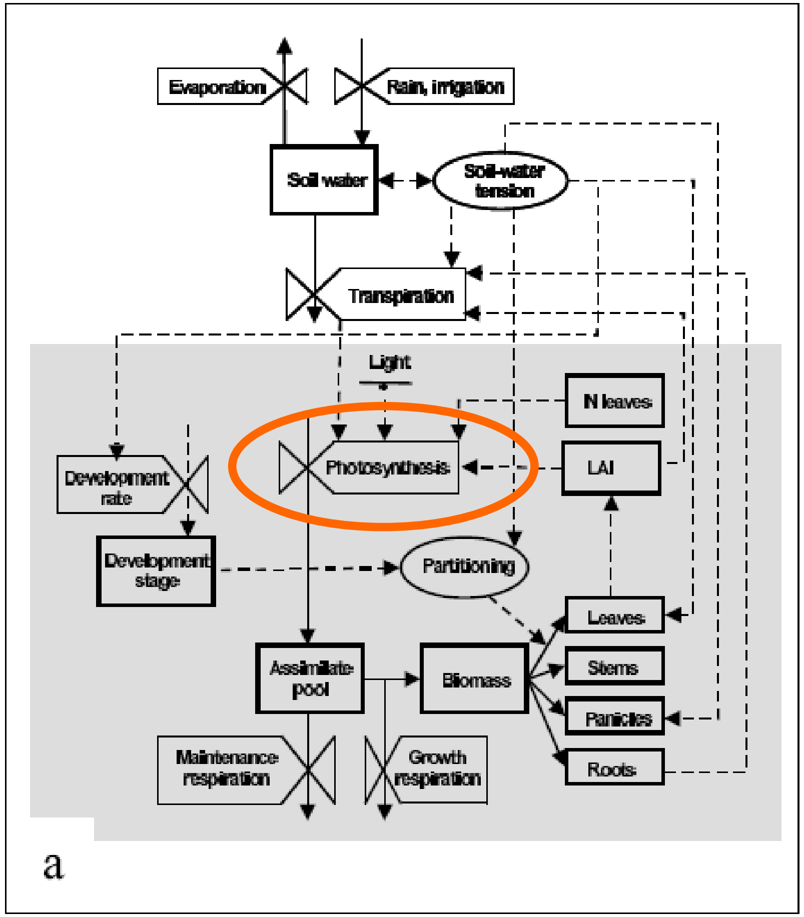
(Tubiello and Fischer, 2007, Tech. Forecast. & Soc. Change)

2°Modelling crops and pastures under elevated CO_2

Functional vs. mechanistic crop models

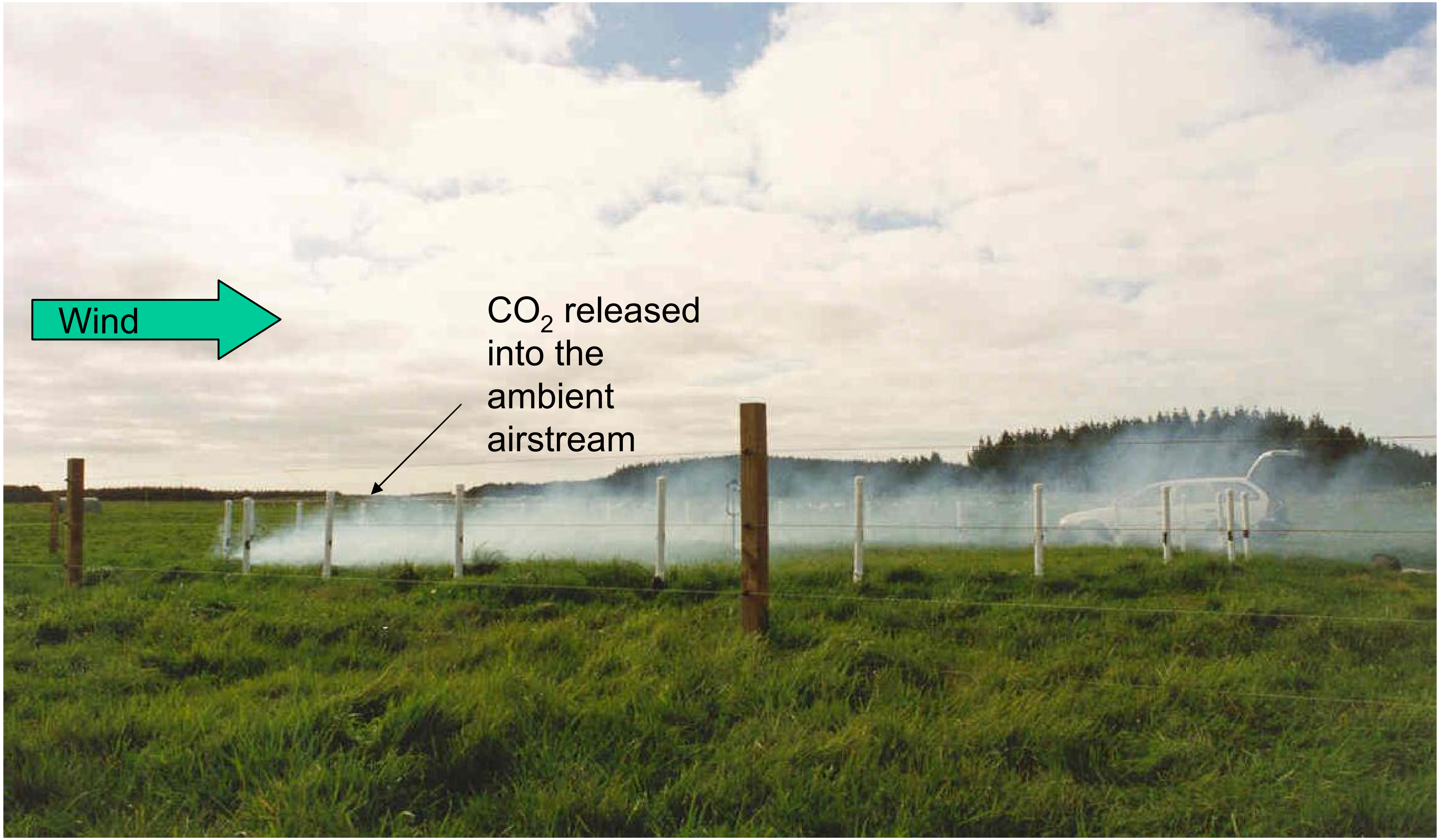


Modules in STICS,
a functional model
(Brisson et al., 2003, EJA)



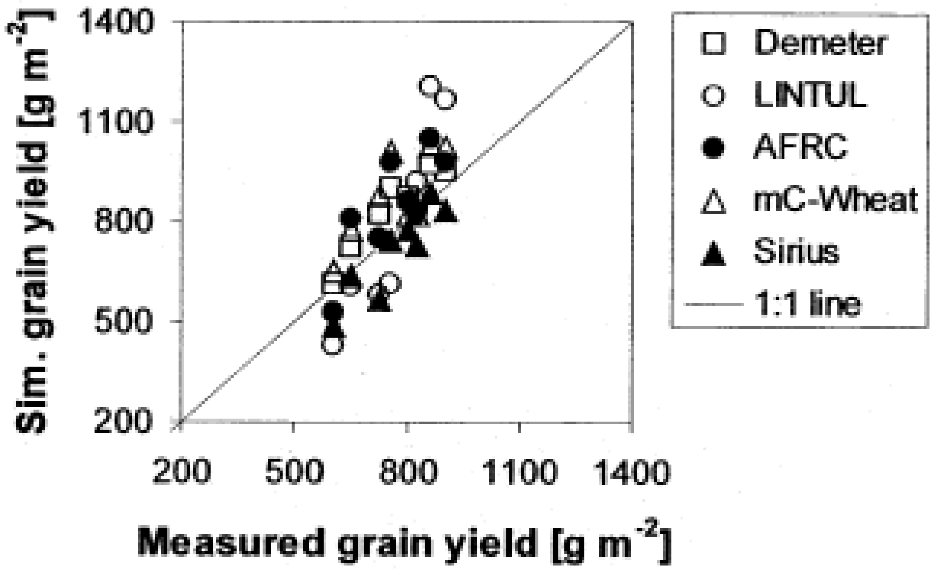
Photosynthetic submodel in Oryza2000,
a mechanistic model
(Van Itersum et al., 2003, EJA)

Elevated CO_2 experiments (FACE, Free Air Carbon dioxide Enrichment)



(New-Zealand, FACE)

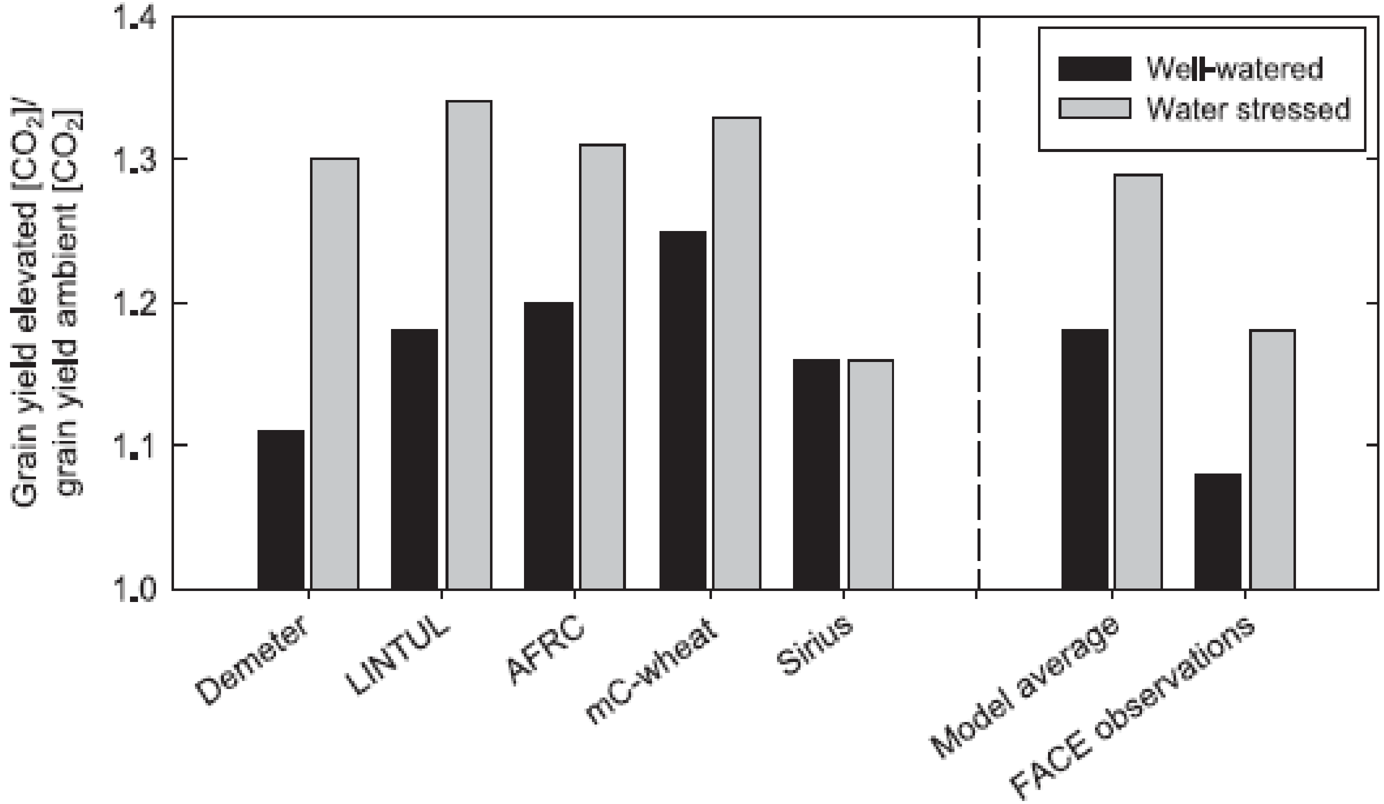
Are grain yields well simulated under elevated CO_2?



Simulated vs. observed (FACE Maricopa) wheat grain yield data.
Two CO_2 and two drought (well watered and water-stressed) treatments

(Tubiello and Ewert, 2002)

Simulated vs. observed CO_2 response ratio

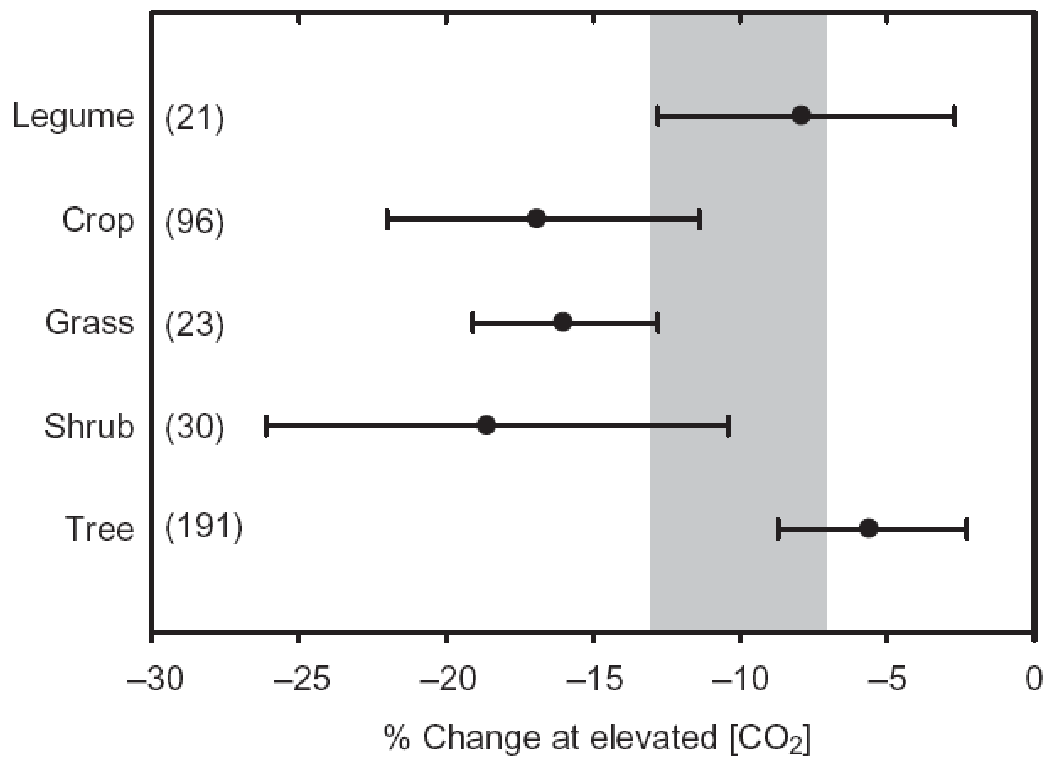


(same data as Tubiello and Ewert, 2002)

Average simulated CO_2 response ratio is higher than observed by +0.1
Interactions between CO_2 and water stress are captured by most models

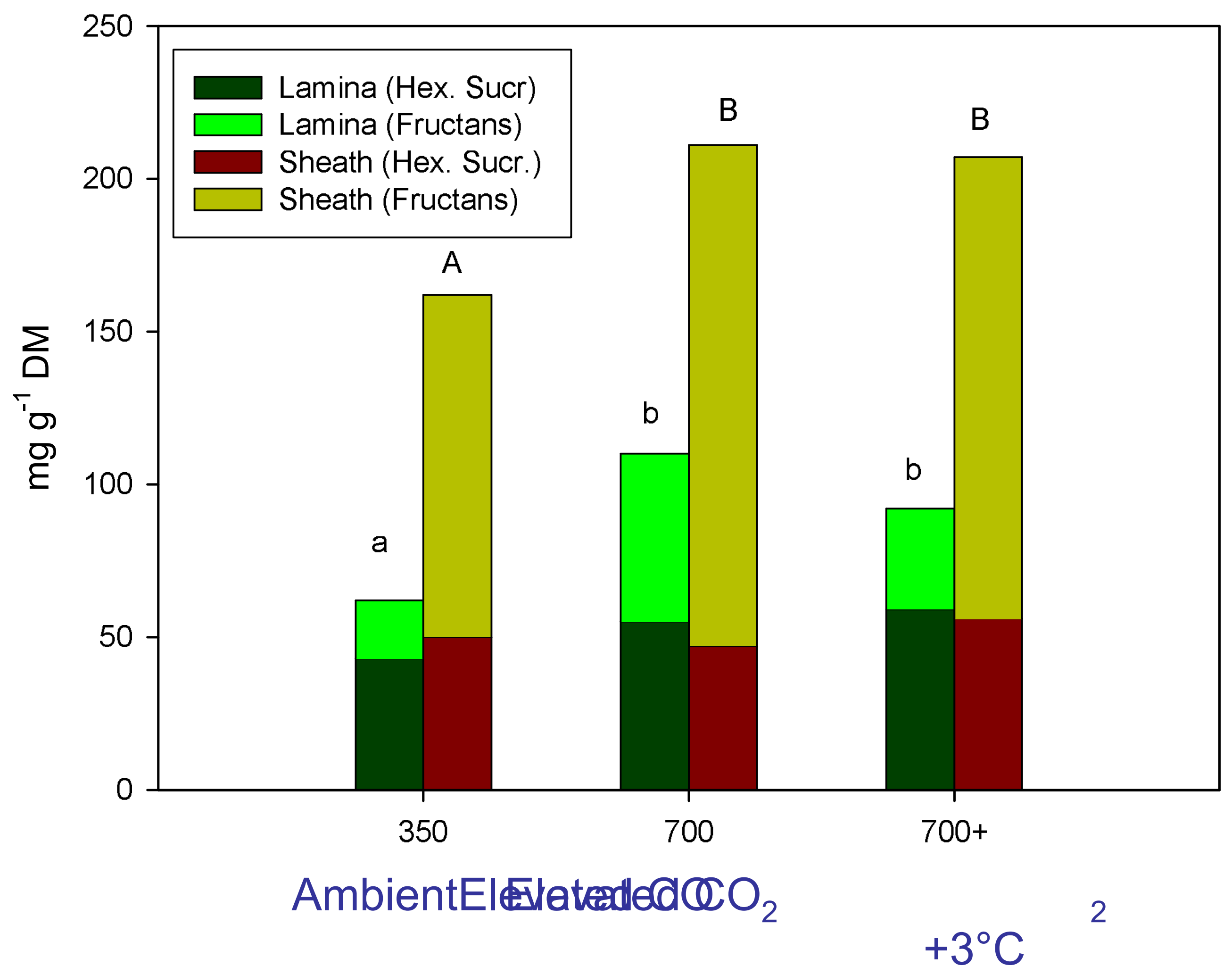
(Long et al. 2008, New Phytol.)

FACE studies: acclimation to elevated CO_2 of maximal carboxylation capacity



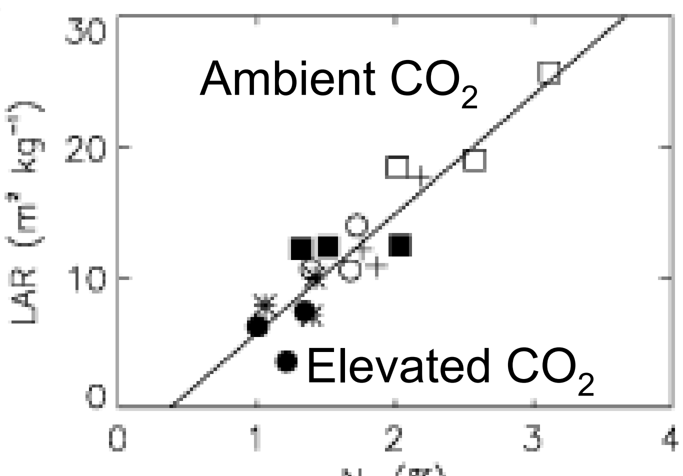
(Ainsworth *et al.*, 2007, PCE)

Observed increase in WSC pools in laminae and sheath of perennial ryegrass monocultures under elevated CO_2 (mean of two N supplies)



(Casella and Soussana, 1997, J. Exp. Bot.)

Observed response to elevated CO_2 in *Lolium perenne* monocultures



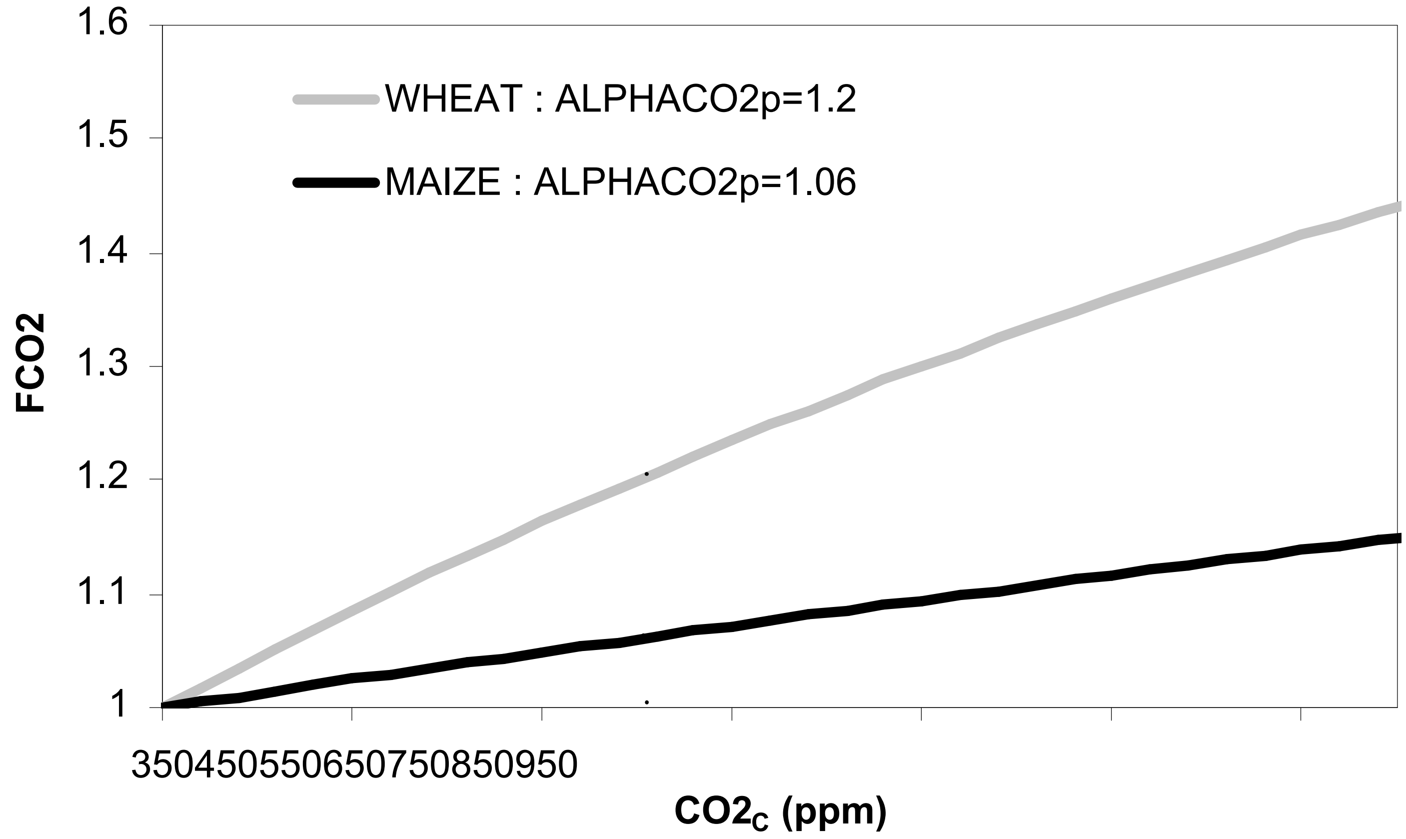
CO_2 induced changes in N content, root fraction and reserve pools are not simulated by functional models

(Soussana et al., 1996; Casella & Soussana, 1997; Calvet&Soussana, 2001)

Leafarea perunit root+shoot massdeclinesunderelevatedCO 2.

This declinecorrelateswiththatinshoot N content

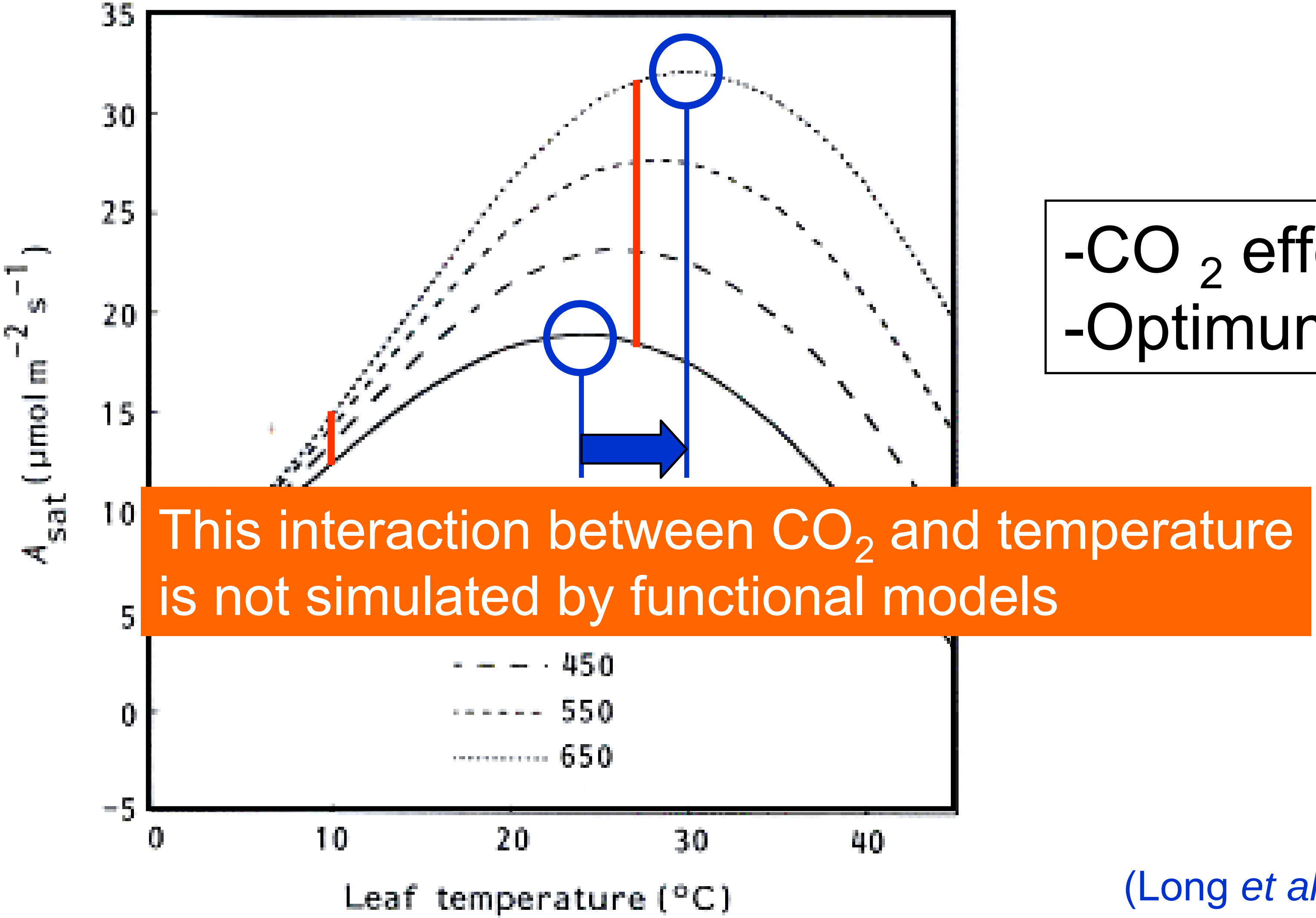
Fixed response ratios to atmospheric CO_2 concentration in functional crop models



STICS model (similar responses for e.g. CERES, EPIC, AEZ)

Interaction between CO_2 and temperature on leaf photosynthesis

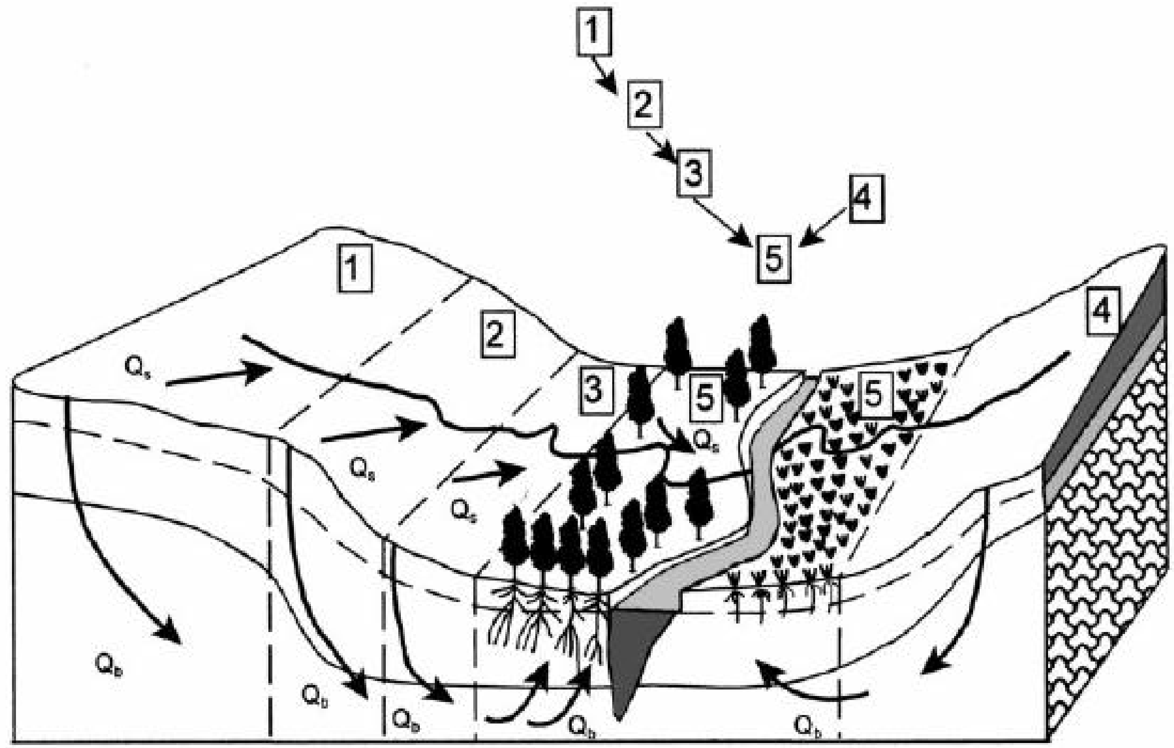
(Farquhar's et al., 1980, biogeochemical model)



-CO_2 effect ↑
-Optimum temp. ↑

(Long *et al.*, 1996)

Issues of scale in coupling with hydrology



Schematic view of lateral water flows in a river basin

Changes in hydrology will directly affect crops and grasslands
Coupled hydrology – crop models needed?

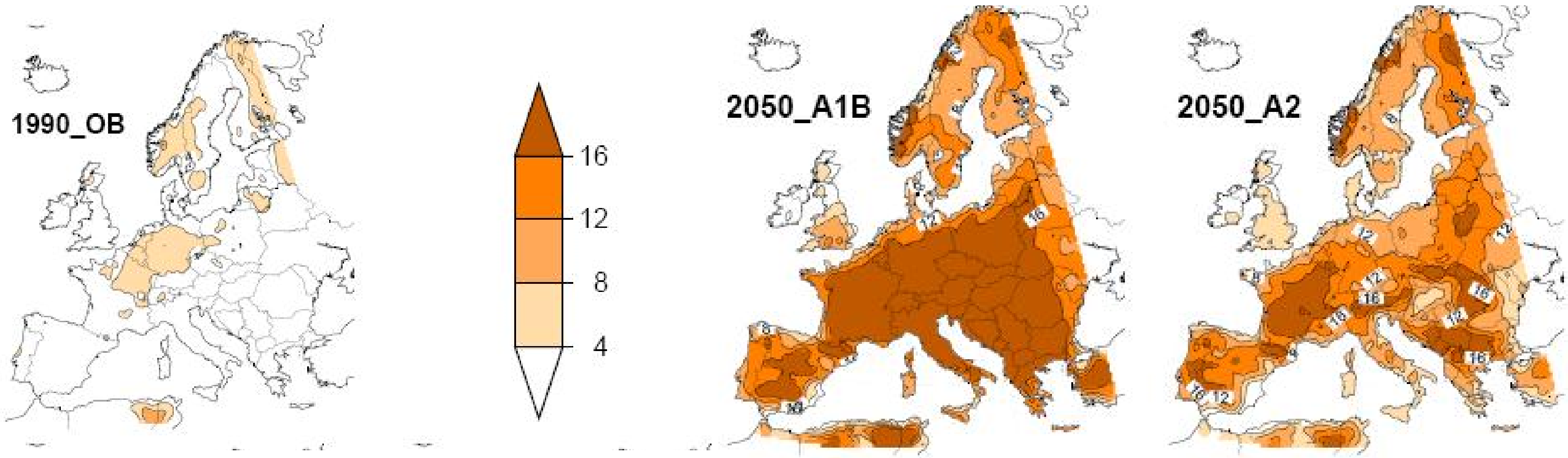
(Schulze, 2000, AGEE)

3°Modelling the impacts of extreme climate events

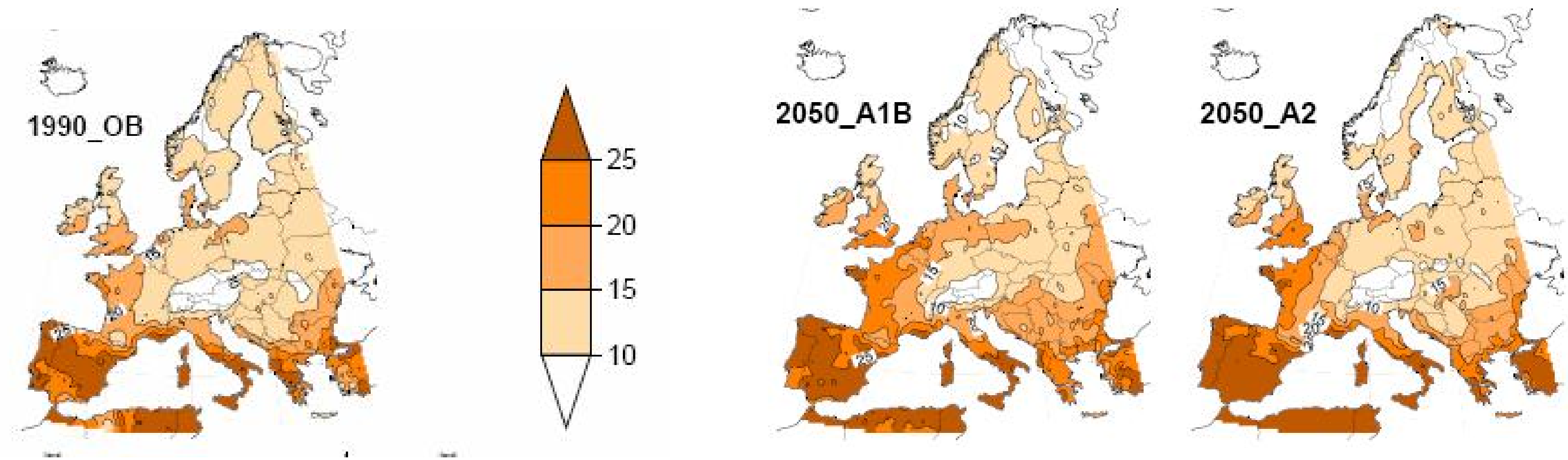
Summer 2003 heat and drought extreme

Increased summer heat wave and drought by 2050

A) Number of consecutive days in a summer heat wave. Mean over 20 yrs

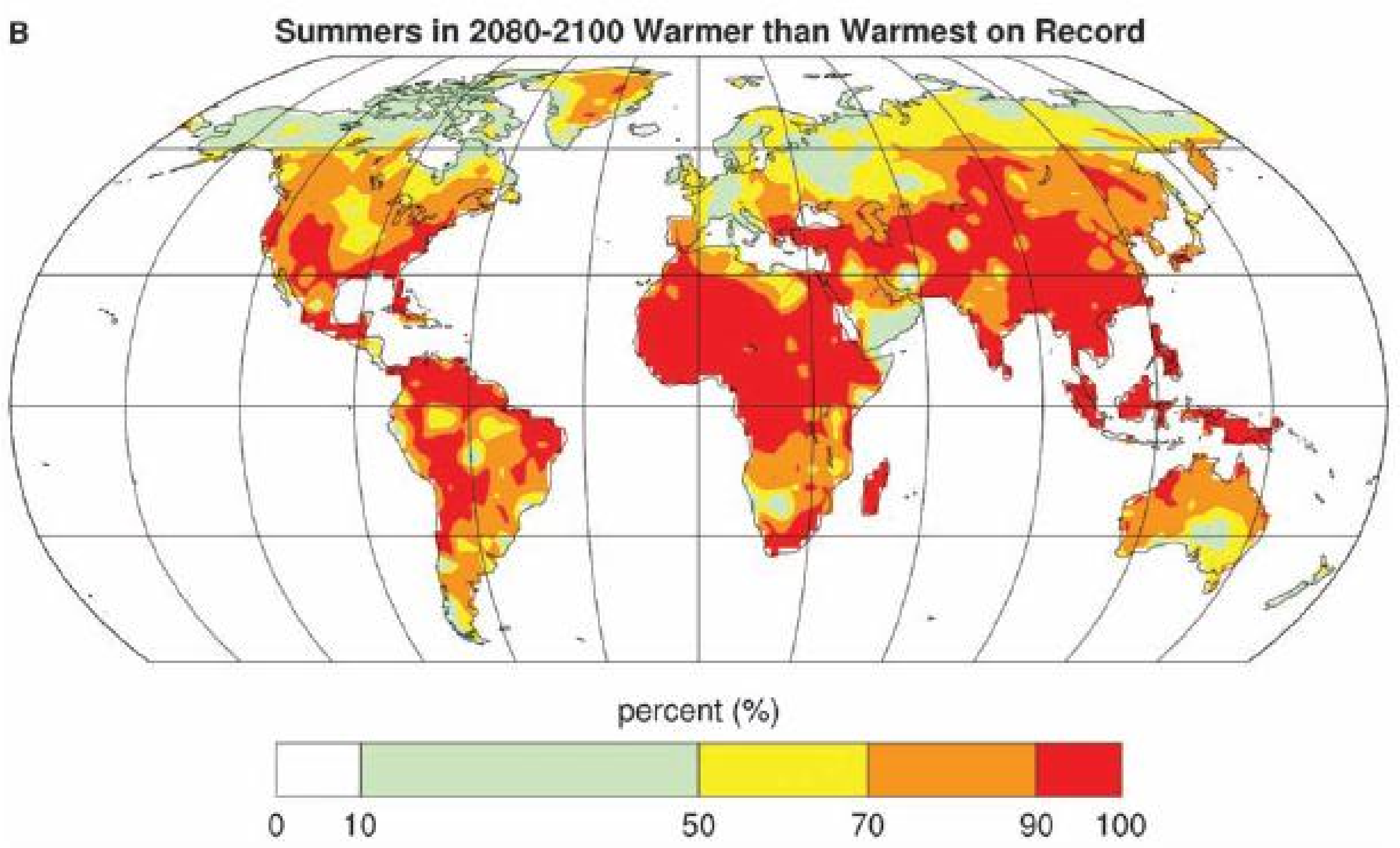


B) Number of consecutive dry days (<1 mm) during summer. Mean over 20 yrs



(ARPEGE model, M Déqué, CNRM, Météo France)

Warmer than warmest summer

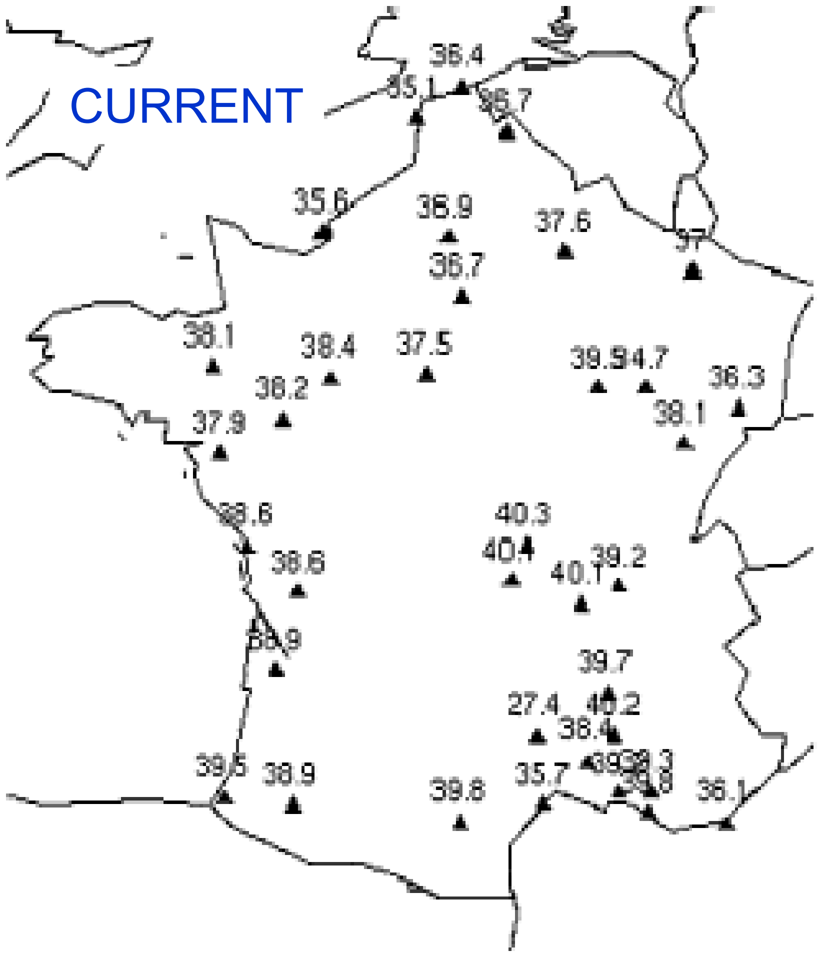


Likelihood in percent of summer average temperature exceeding by2090 highest observed temperature on record

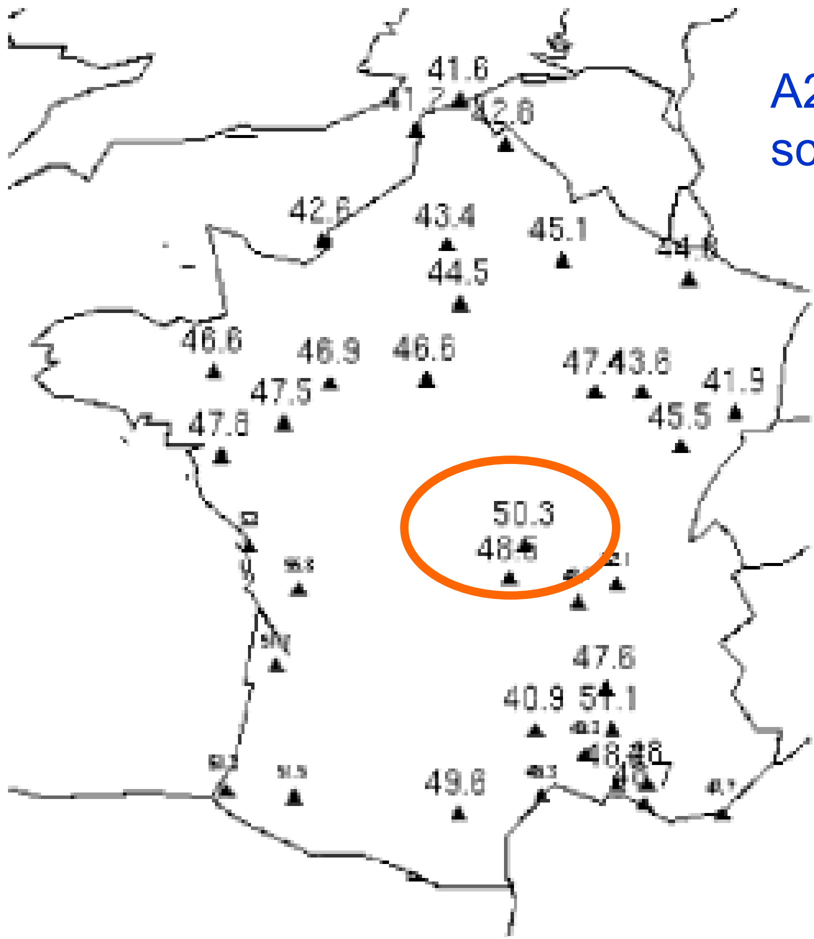
(Battisti and Naylor, 2009, Science)

Projected 100 yr return levels for the end of century compared to currently observed

CURRENT

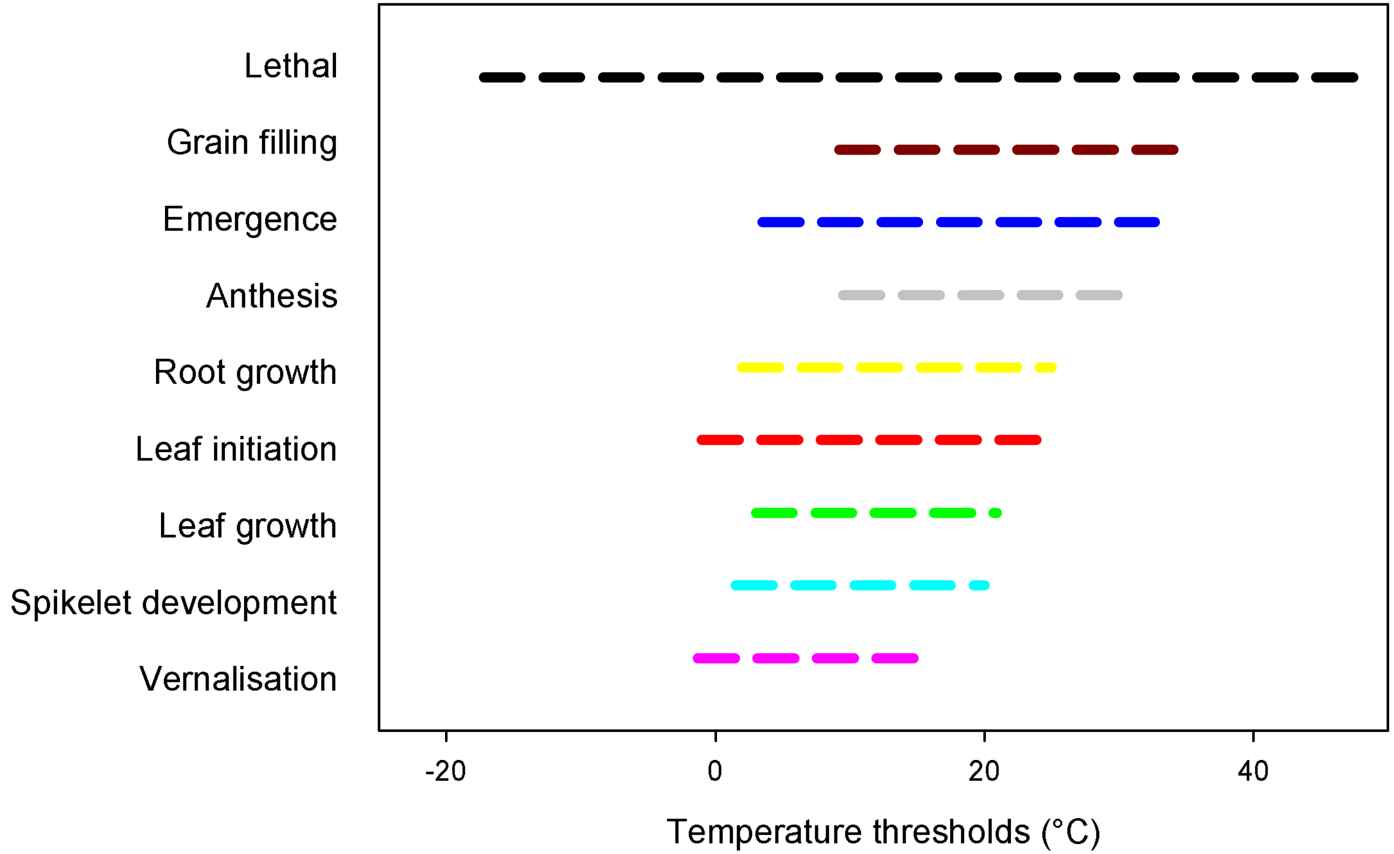


A2 scenario



(Parey et al., 2008, Clim. Dyn.)

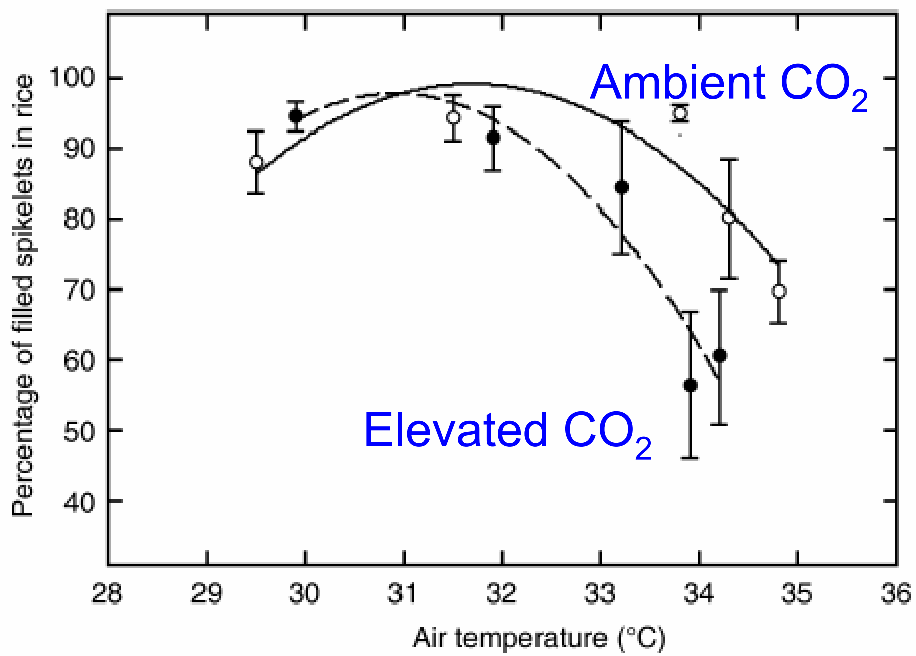
Temperature thresholds in wheat



Complex interactions between phenology and warming impacts
Missing in some crop models

(after Porter and Semenov, 2005)

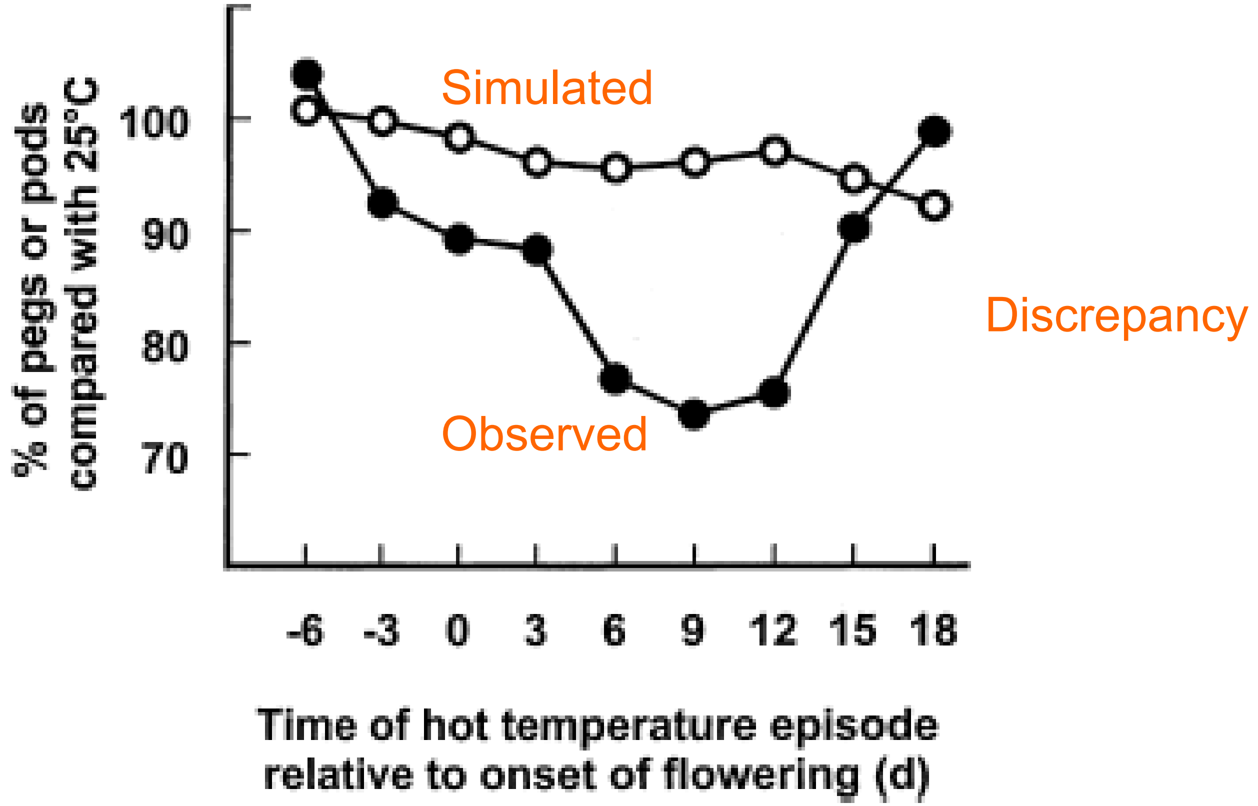
Interactions between CO_2 and temperature for spikelets number in paddy rice



Negative interaction
Modelled?

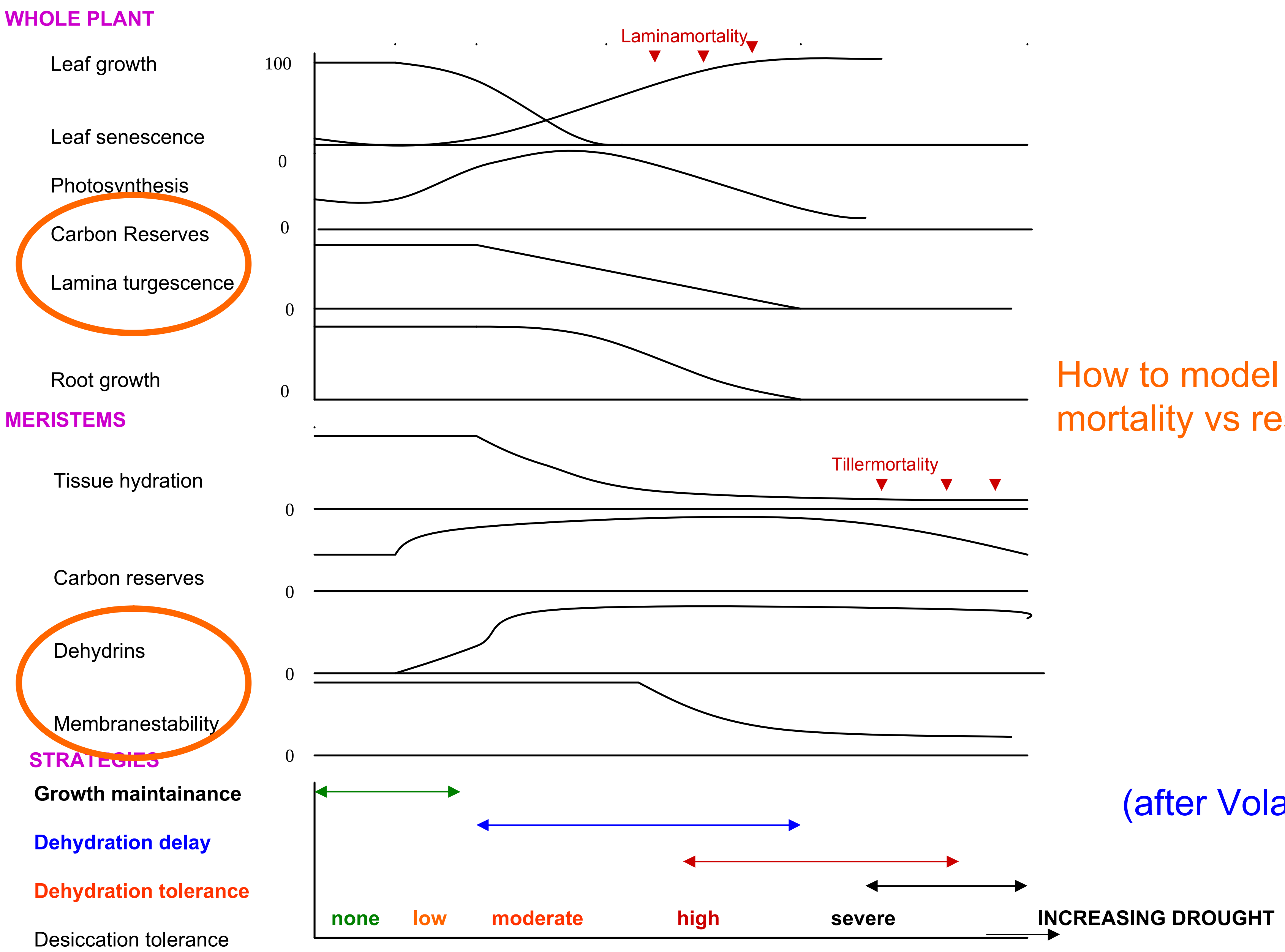
(Ziska and Bunce, 2007, N Phytol., after Matsui et al., 1997)

Simulated vs observed effect of a week at +10°C compared to a 28°C control in groundnut



(Wheeler et al., 2002)

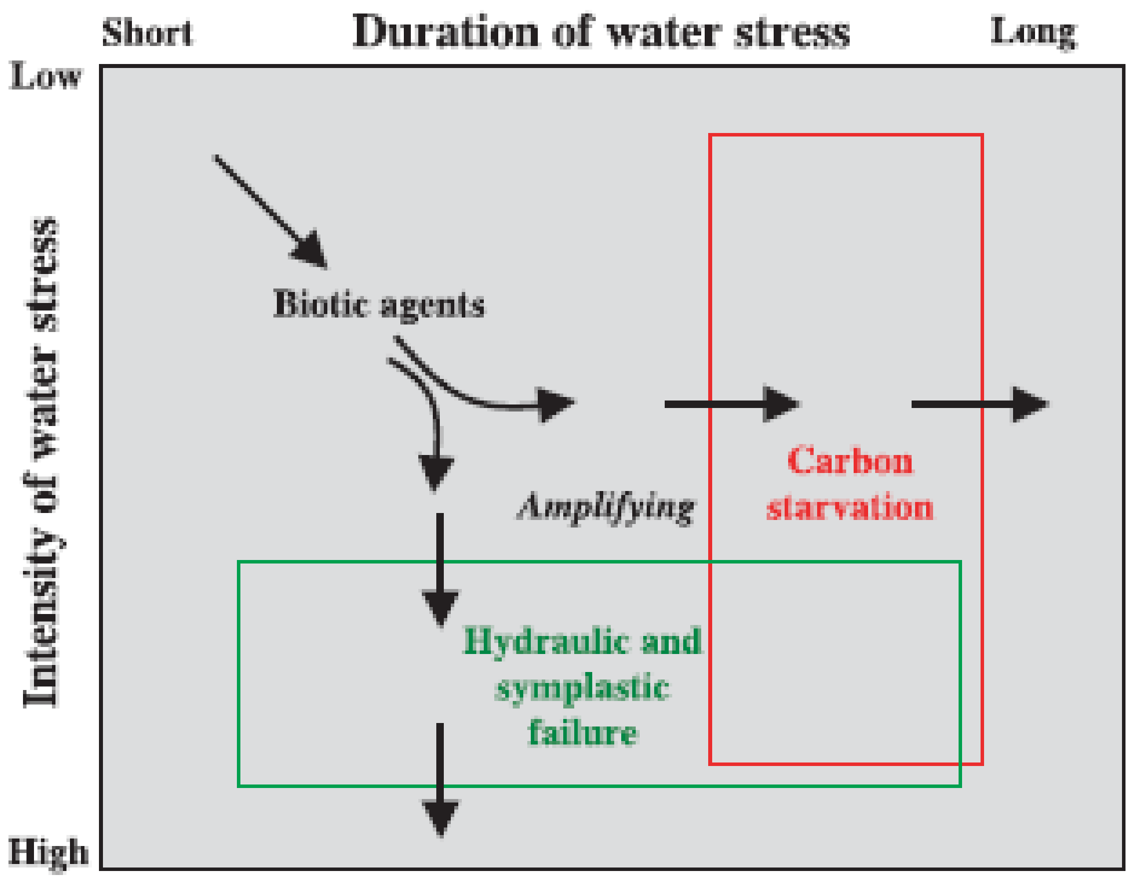
Perennial grasses strategies under prolonged droughts



How to model mortality vs reserves?

(after Volaire, 2008)

Drought survival vs. the duration and intensity of water stress

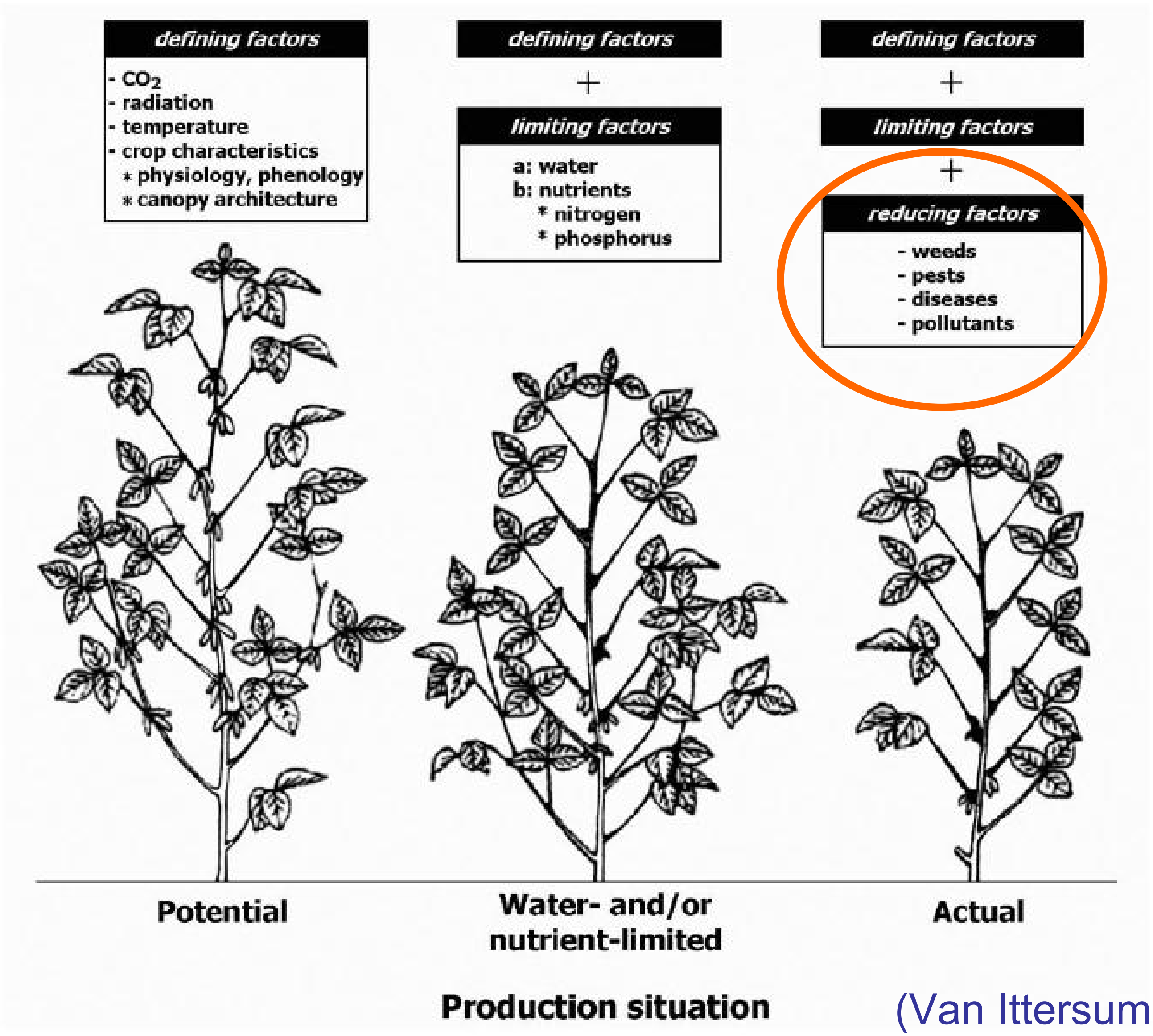


Theoretical relationships based on the hydraulic framework

(Mc Dowell et al., 2008, N Phytol.)

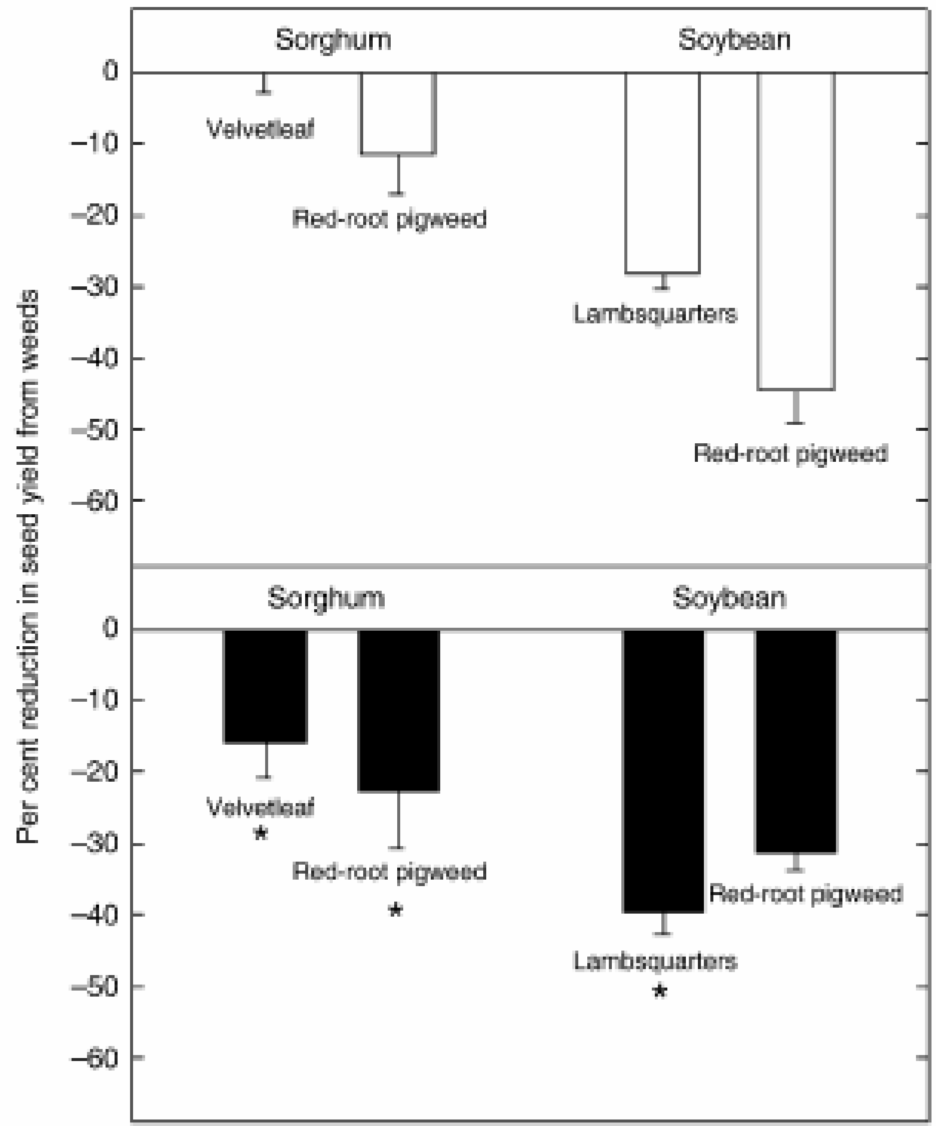
4°Modelling the role of biotic interactions and of pollutants

Role of pests, diseases and pollutants: reducing factors



(Van Ittersum et al., 2003, EJA)

Observed % reduction in seed yield as a function of competition from C_3 and C_4 weeds



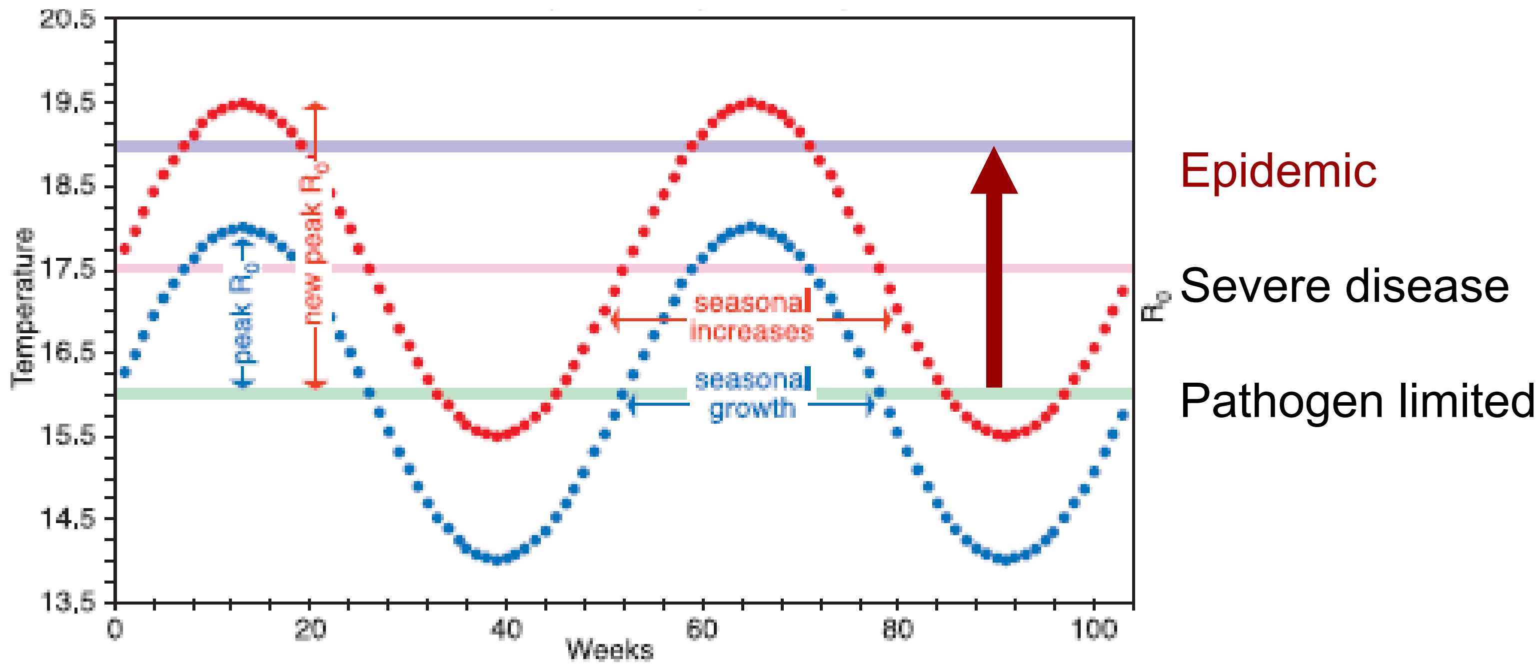
Ambient CO_2

Elevated CO_2

(*, interaction with CO_2)

(Ziska and Bunce, 2007, N Phytol.)

Response of pathogen growth rate to temperature and 1.5°C warming



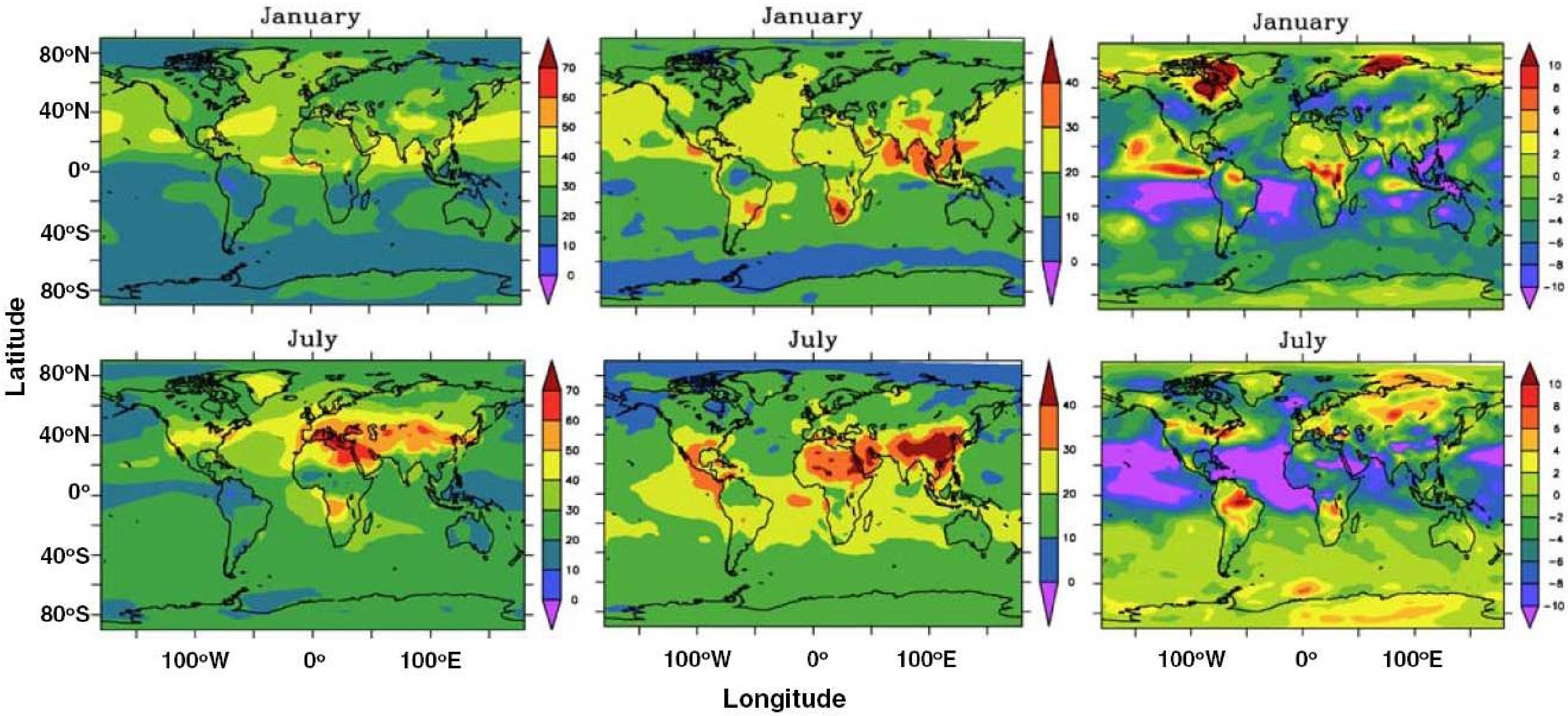
(Harvell et al., 2002, Science)

Modelling pests and pathogens

- Forecasting models using climate variables can effectively predict outbreaks for some crop diseases.
  - Potato late blight (*Phytophora infestans*) is correctly forecasted 92% of years on the basis of number of days of rain,
  - Rice blast (*Pyricularia oryzae*) models based on temperature and moisture forecast when an epidemic will start and when to apply fungicidefor optimal control.
- Coupling disease forecasting models with models predicting epidemic impacts on crop productivity under climate change is needed.
- The rate of adaptation and evolution is an important unknown in any prediction of climate impacts.

(Harvell et al., Science, 2002)

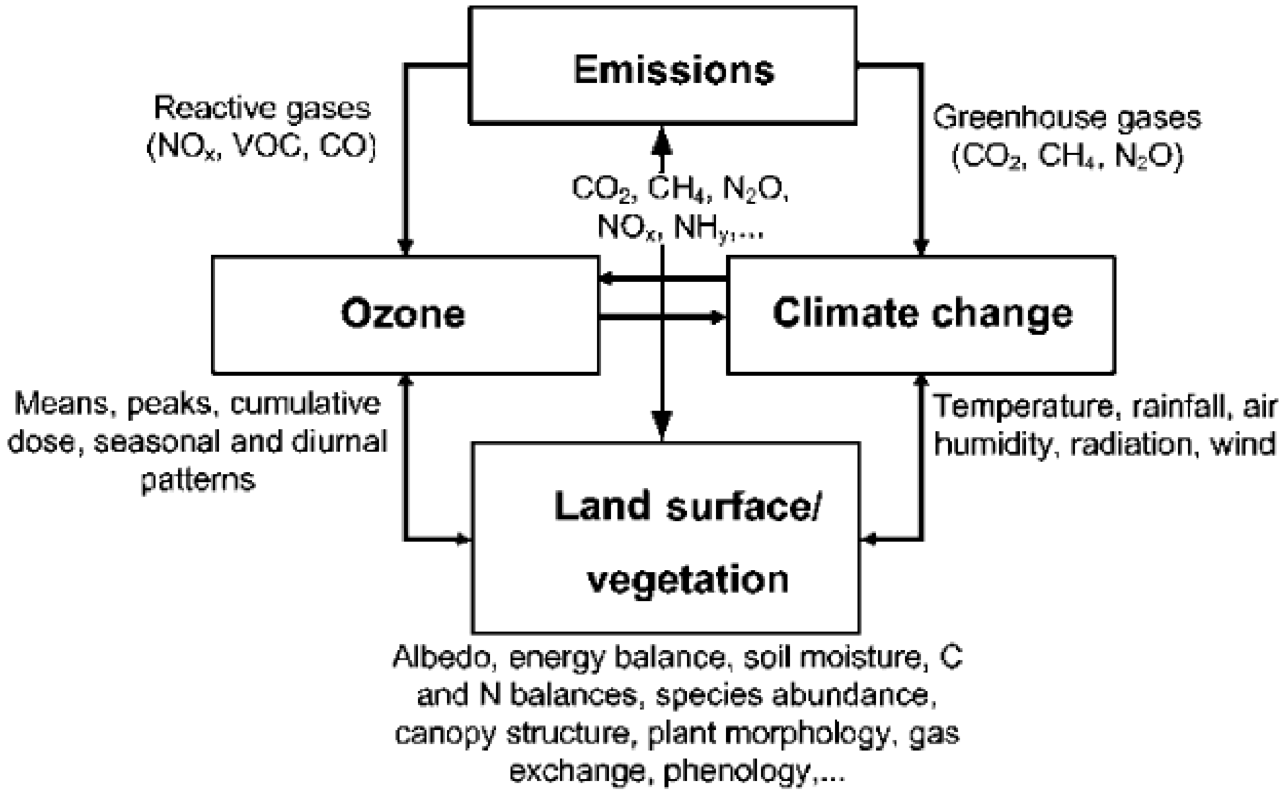
Projected increase in surface ozone concentration (ppb) by 2100



Present dayIncreased anthropogenicInteractions with climate
ozone emissions change

(Zheng et al., 2008)

Scheme of interactions between vegetation, climate and ozone pollution



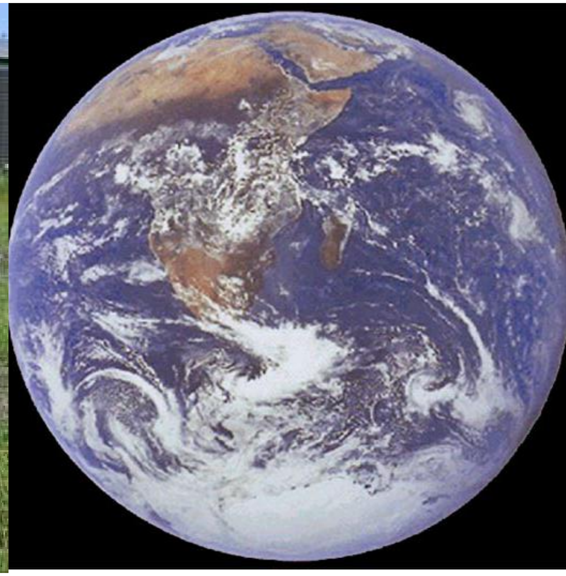
Interactions included in some global biosphere models (e.g. ORCHIDEE)

(Fuhrer, 2009, Naturwissenschaft)

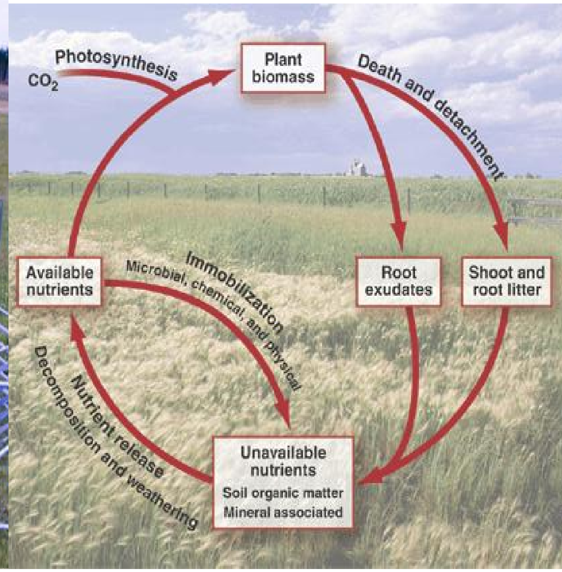
Perspectives

- Improving climate change impact projections will require a major effort combining:
  - Further crop/pasture model developments
  - Development of international data bases
  - Extensive model-data and model-model intercomparison
  - New generation of CO_2 experiments (Ainsworth et al., 2008) and of climate change experiments
  - Setting quality standards for an ensemble of crop and pasture models used for generating projections

- Bridging contrasted scales (from field to global) implies coupling crop & pasture models with:
  - soil biota models,
  - hydrology models,
  - disease spread, weed dispersion models,
  - Atmospheric pollution models
  - Farm scale adaptation models
  - Socio-economic models



Thank you


Photosynthesis
CO_2
Plant biomass
Death and detachment
Root exudates
Shoot and root litter
Available nutrients
Immobilization
Microbial, chemical, and physical
Nutrient release
Decomposition and weathering
Unavailable nutrients
Soil organic matter
Mineral associated