WCRP World Climate Research Programme
WCRP OPEN SCIENCE CONFERENCE
CLIMATE RESEARCH IN SERVICE TO SOCIETY
24-28 October, Denver, CO, USA

Tyndall°Centre® for Climate Change Research
UEA University of East Anglia

Quantifying the Impact of More Frequent and Stronger Extreme Climatic Events on Global Crop Yield

Delphine Deryng
Rachel Warren & Navin Ramankutty

d.deryng@uea.ac.uk

October 2011

Impact of Climate Change

- Global assessment of the impact of climate change on agricultural productivity

(Gornall et al., 2010, Nelson et al., 2009, Parry et al., 2005)

1. General decrease in global crop yield due to higher heat stress
2. Longer growing season in temperature-limited regions
3. Expansion of suitable cropland area in colder regions

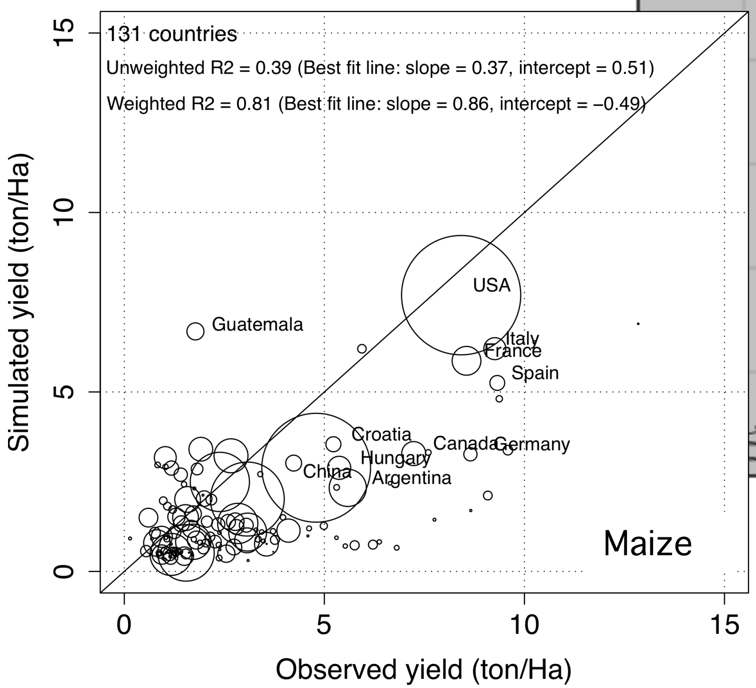
→ Limited to evaluate the impact of change in mean climate

- Big uncertainties!

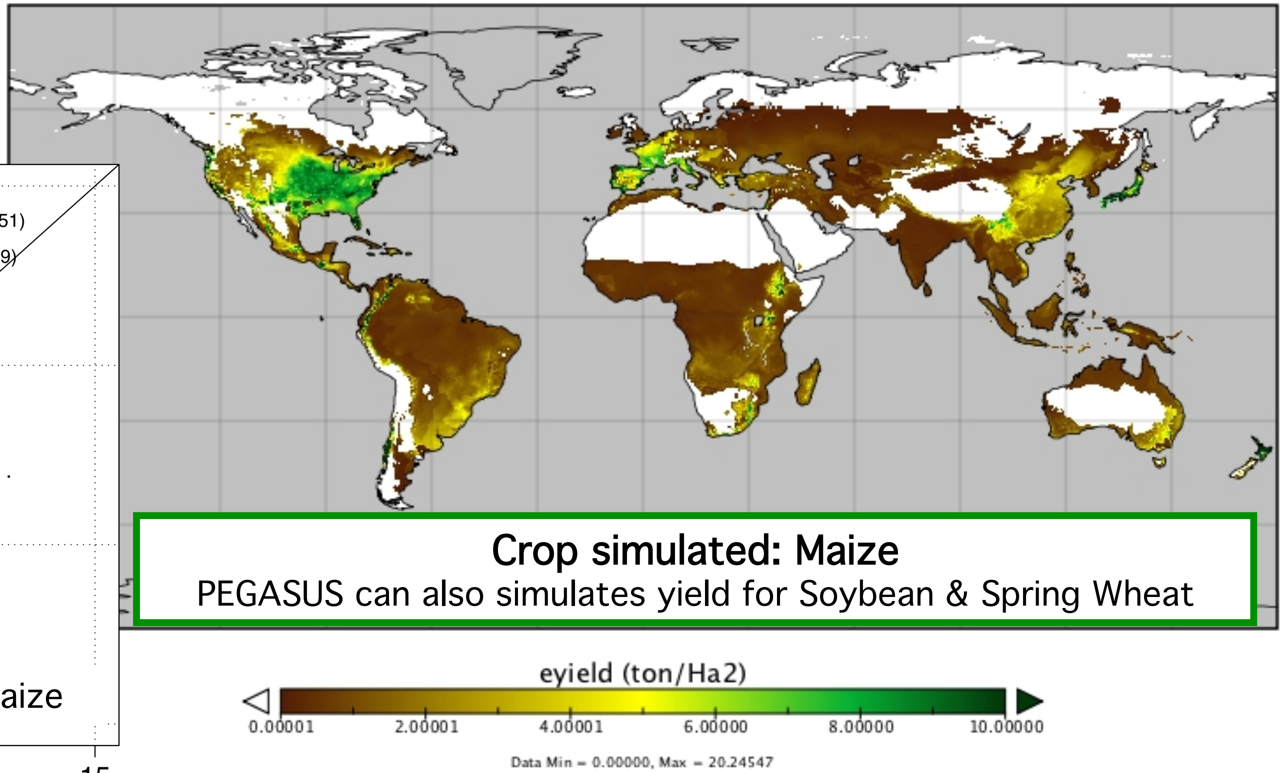
1. Farmers adaptation options
2. Impact of climate variability
3. CO_2 fertilization effect
4. Indirect impacts:
   - increase risk of diseases
   - CC impact on water resources for irrigation

METHOD

- Simulation at the global scale using a geospatially explicit crop yield model : PEGASUS
- Deryng et al. (2011): Benefits of farmers adaptation (choice of crop cultivars, planting dates decision) to change in mean climate



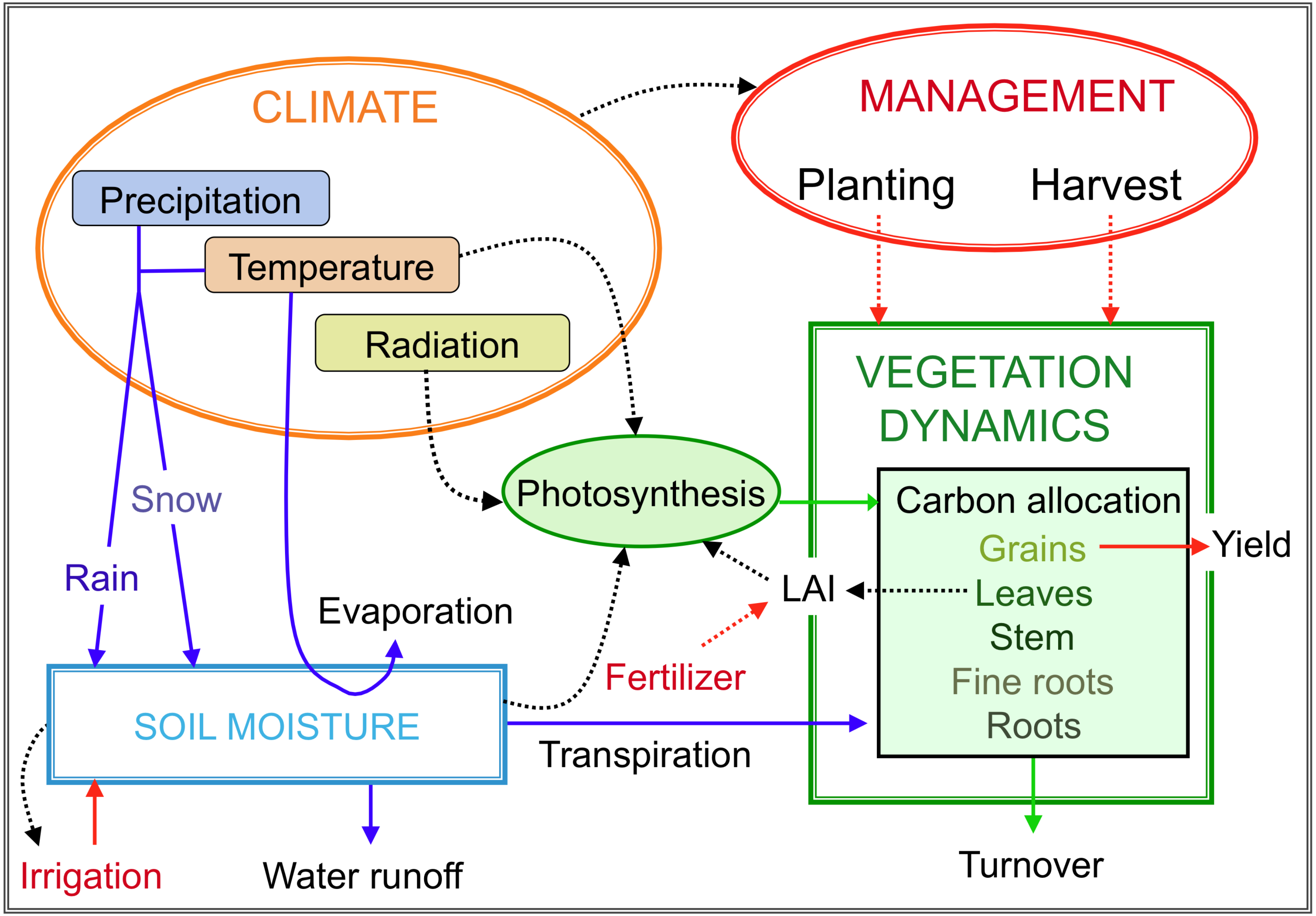
Maize Simulated Yield



Crop simulated: Maize
PEGASUS can also simulates yield for Soybean & Spring Wheat

1. PEGASUS

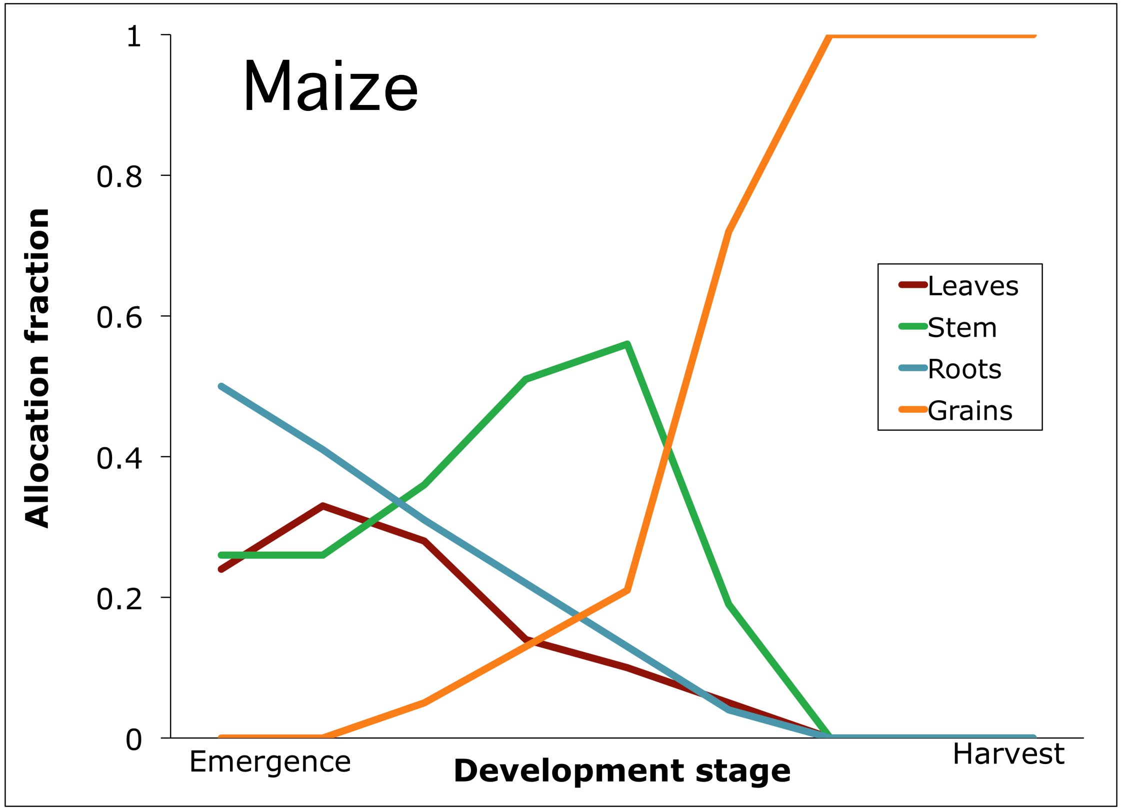
Predicting Environmental Goods And Services Using Simulations



Vegetation Dynamic

Biomass production is calculated for each day from the emergence of the crop until harvest time

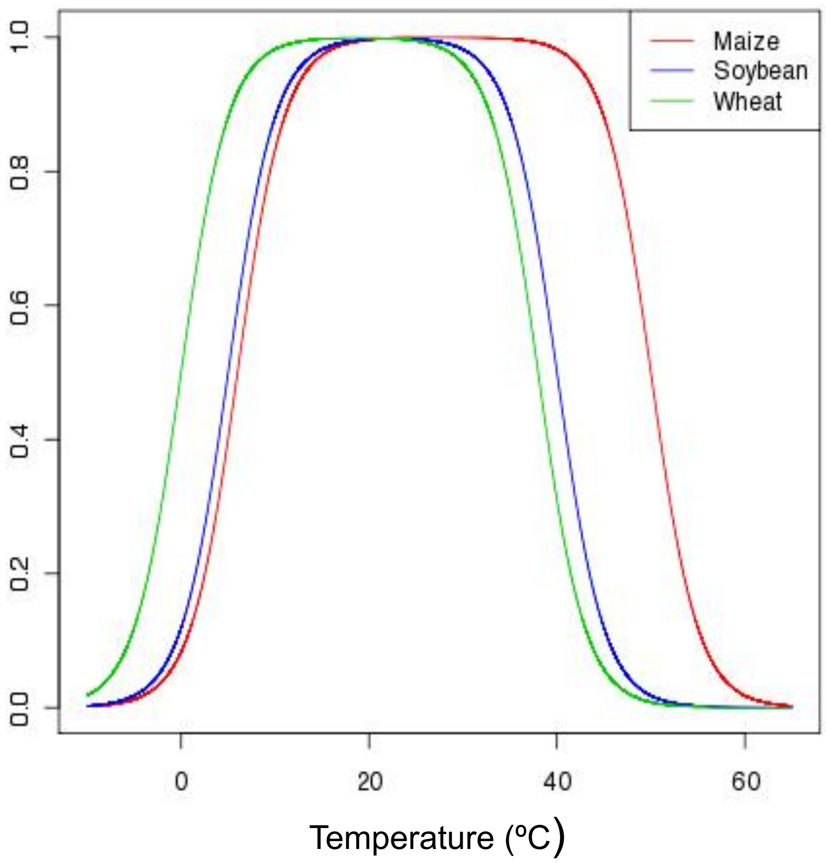
Biomass production is allocated to different part of the crop: leaves, stem, roots and grains



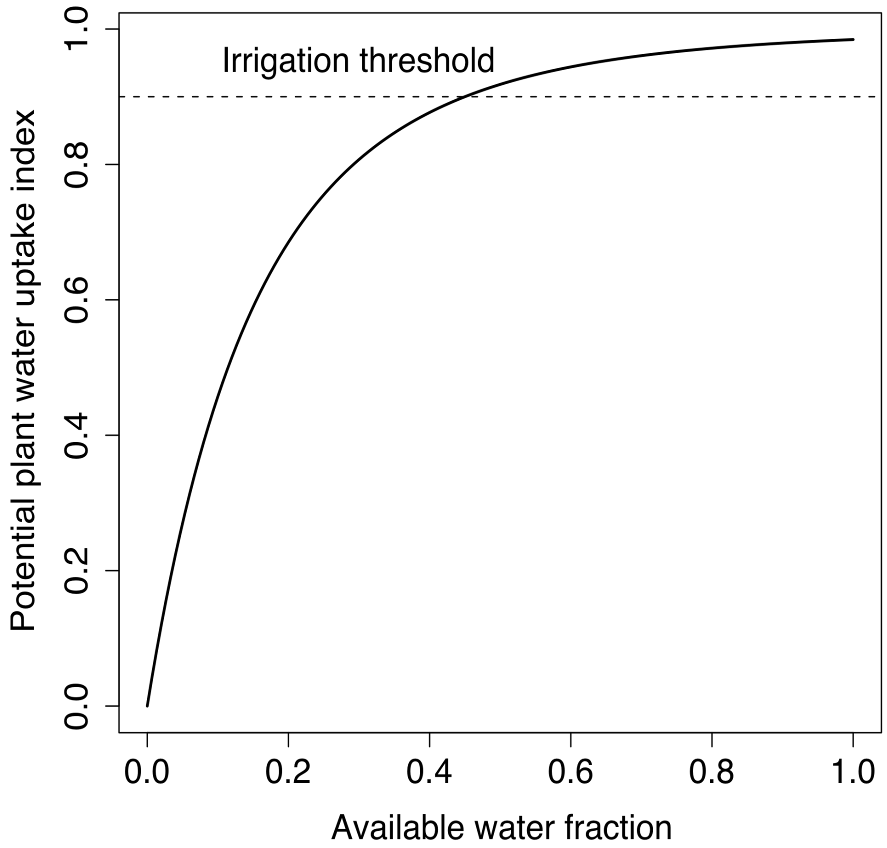
Dynamic allocation fraction throughout the crop development

Temperature & Water Stress factors

Temperature Stress Factor

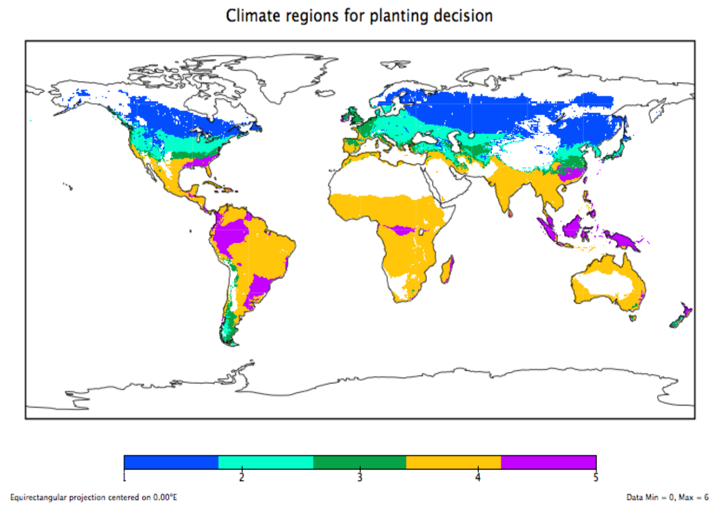


Water Stress Factor



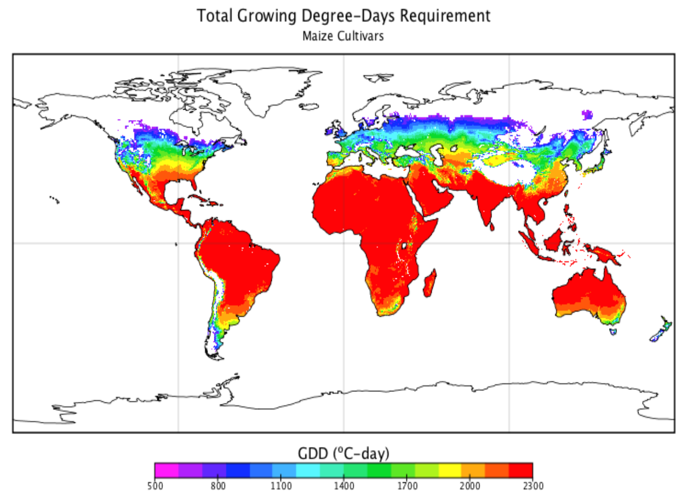
Adaptation Options

1. Planting date decisions are driven by mean climate conditions:
   - Temperature-limited regions: planting occurs when it gets warm enough to allow the plant to grow (spring-type crops)
   - Moisture-limited regions (not temperature-limited): planting occurs at the start of the rainy season



2. Selection of crop cultivars:
   - Different cultivars have different thermal time requirements
   - Farmers select cultivars of a crop adapted to the local climate

→ Ex. cultivars grown in colder climates have smaller thermal time requirement, thus shorter growing period



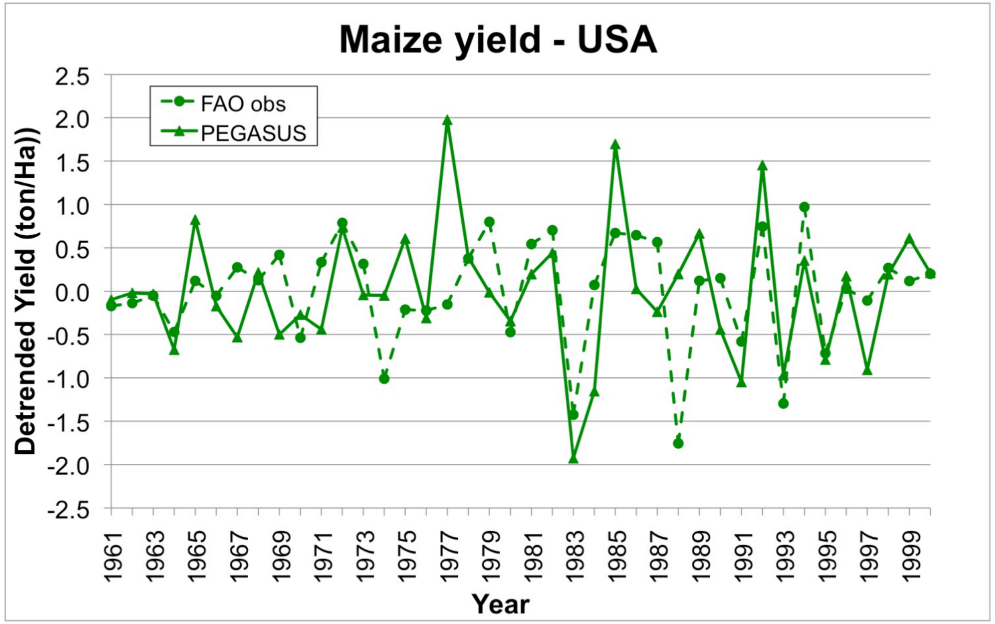
2. HISTORICAL YIELD ANALYSIS

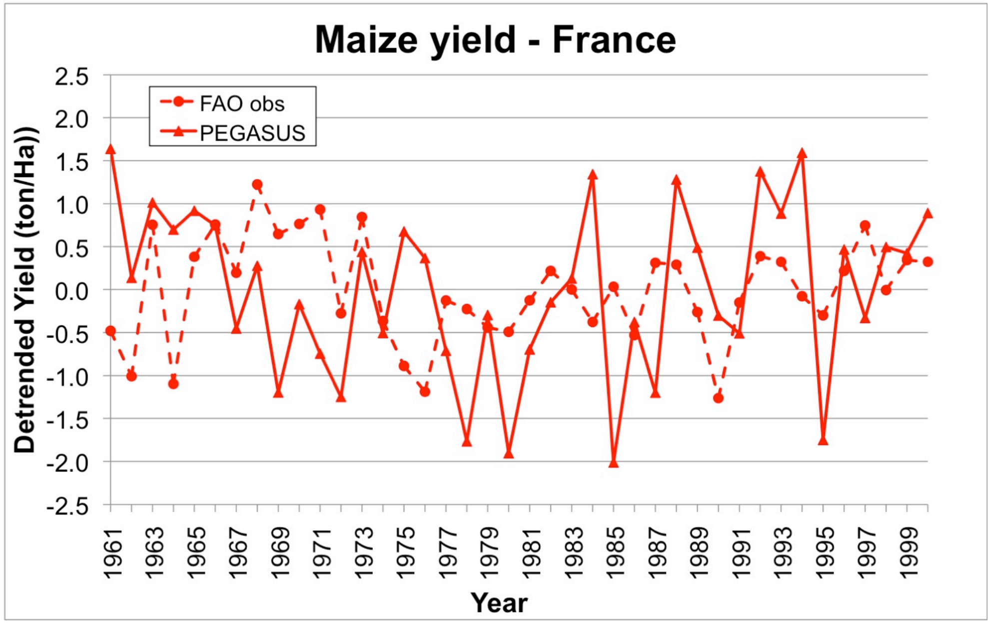
- Climate data: NCC* dataset to create daily data of temperature, precipitation, fraction of sunshine hours (Ngo-Duc et al. 2005)

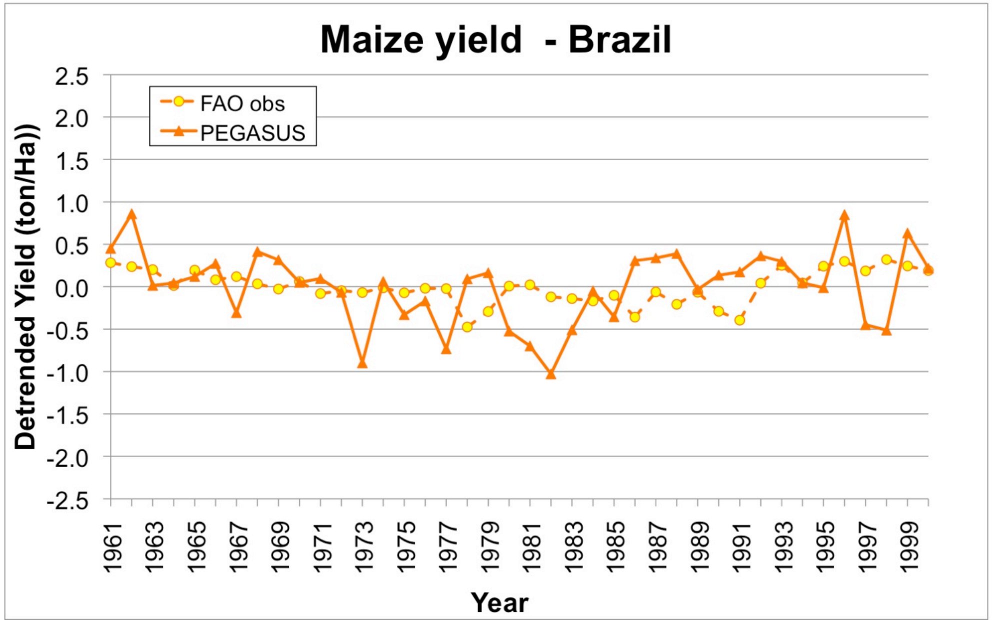
- Period: 1961–2000 (analysis of FAO national average yield data)

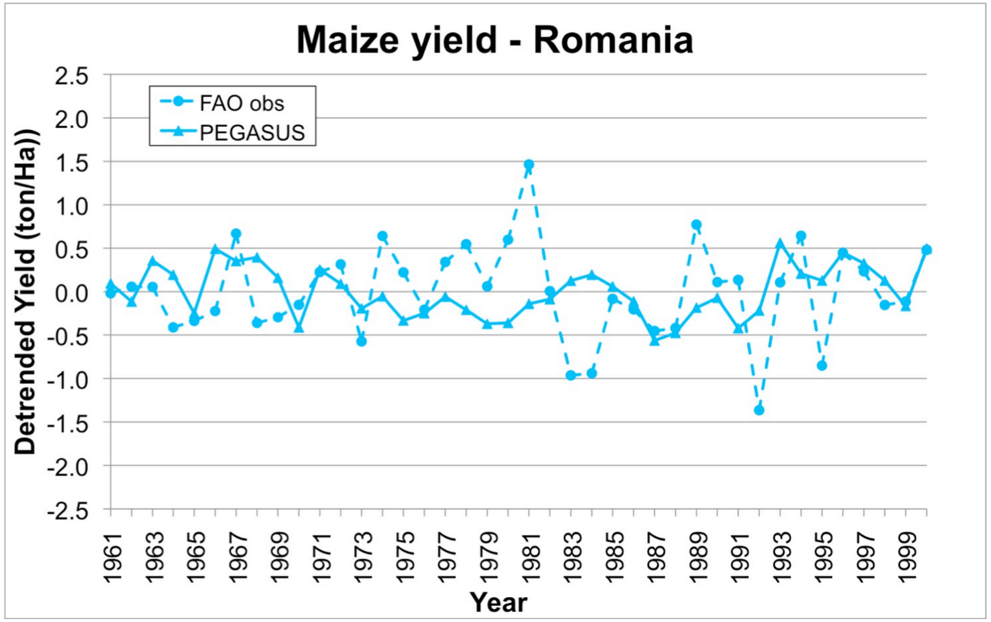
*NCC (National Centers for Environmental Prediction/National Center for Atmospheric Research Corrected by Climate Research Unit) is the near-surface meteorological data with a 6-hourly time step from 1948 to 2000 and a spatial resolution of 1x1 degree over the land surface

Inter-Annual Variability

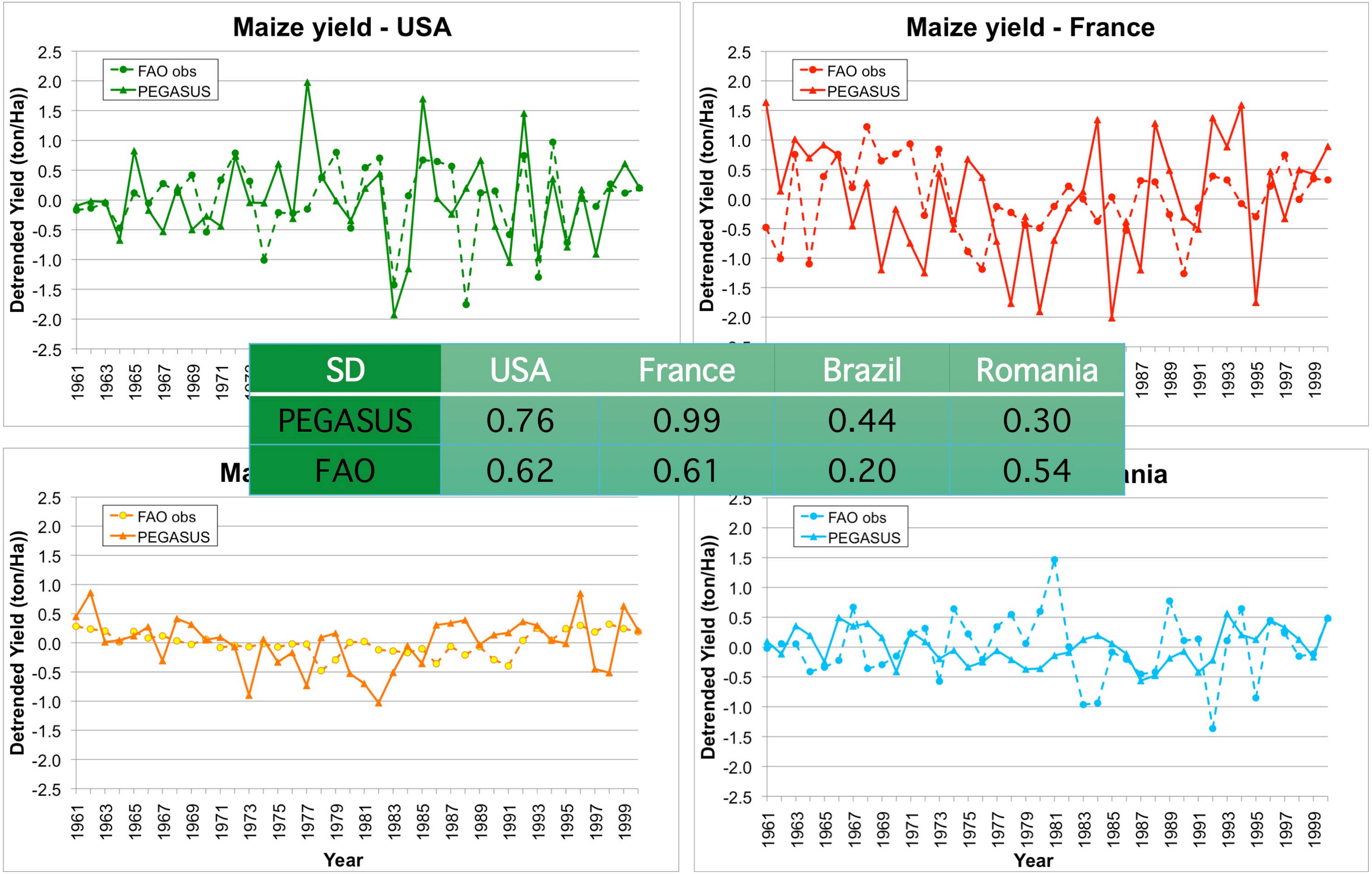








Inter-Annual Variability

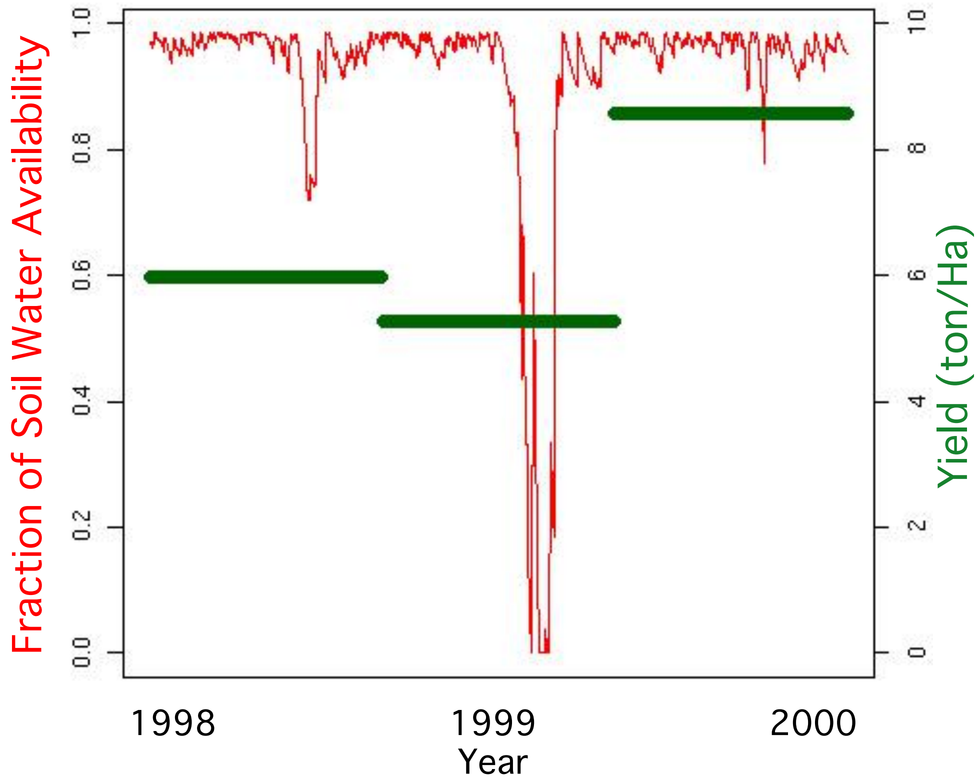


SD	USA	France	Brazil	Romania
PEGASUS	0.76	0.99	0.44	0.30
FAO	0.62	0.61	0.20	0.54

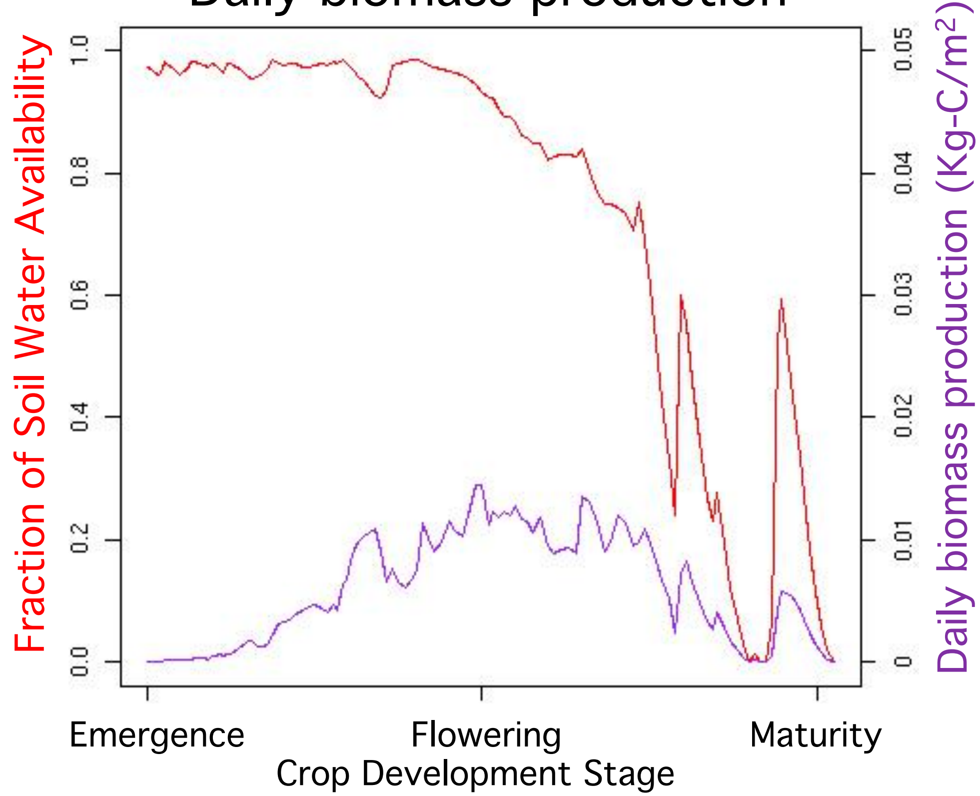
Daily Variability

Pixel co-ordinates: 85.25W 37.25N (Kentucky, United-States)

3 consecutive years
Soil Water & Yield

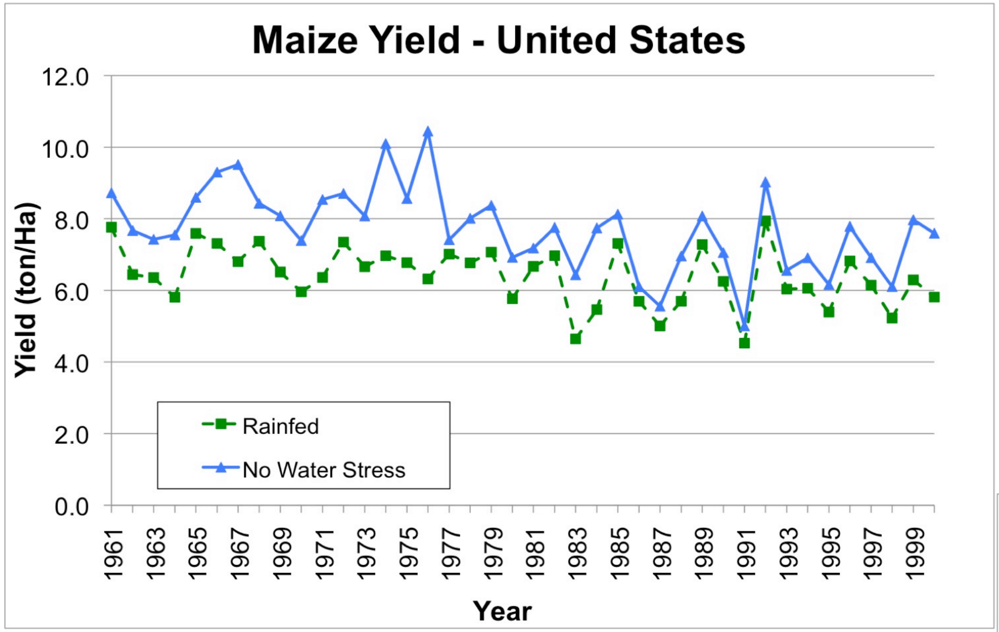


1 year: 1999
Soil Water &
Daily biomass production



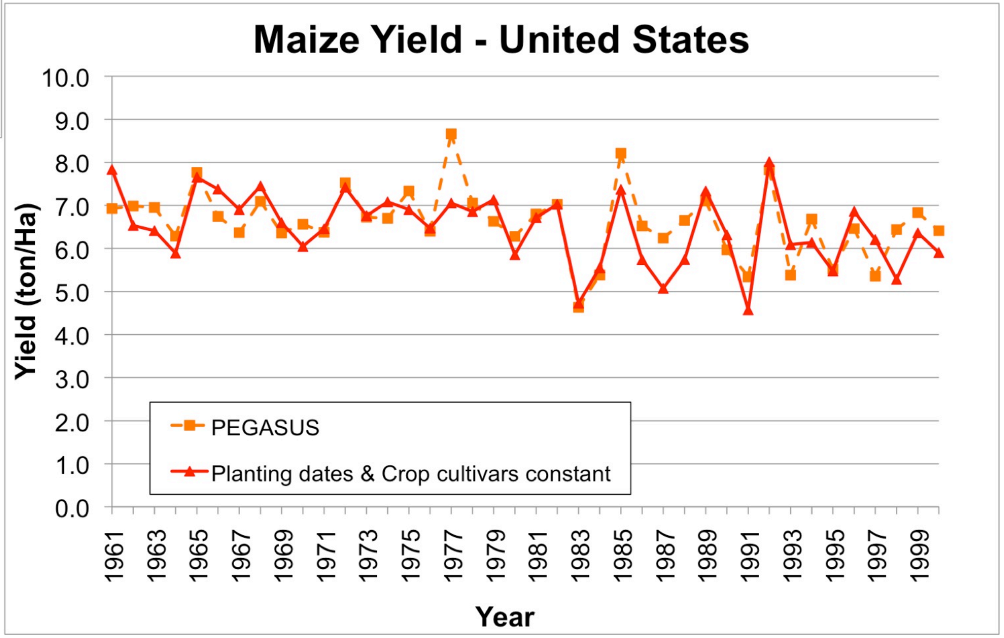
Farmers Adaptation
Model Sensitivity Analysis

Irrigation under water stress



Ton/Ha	Rainfed	No Water Stress
Mean	6.5	7.8
SD	0.76	0.97

Adapting planting dates & choices of crop cultivars



Ton/Ha	Adapting P/C	P/C constant
Mean	6.6	6.5
SD	0.76	0.75

3. FUTURE CROP YIELDS

- Monthly Climate data from CIAS

Community Integrated Assessment System (Warren et al., 2008)

  – Global GHG emissions scenarios (Stern, SRES, RCPs)
  – Global climate model emulator: MAGICC 6
  – Downscaling climate module: ClimGen

→ 18 different Global Climate Models (GCMs)

→4 Representative Concentration Pathways (RCPs) radiative forcing scenarios (Moss et al., 2010)

→Monthly mean climate data from ClimGen

Stochastic Weather Generator

- Daily precipitation:
  - Is today wet or dry? Two-states first order Markov chain according to the number of wet days per month

  → Probability of precipitation today depends on yesterday weather condition: Today is more likely to be rainy if yesterday was rainy than if yesterday was dry!

  → Gamma distribution of precipitation centered on monthly average precipitation per wet day

- Daily temperature and fraction of sunshine hours
  - Multivariate model: mean and standard-deviation of each variable are tied to the wet or dry status of the day

Richardson's weather generator:

Parlange & Katz (2000), Richardson and Wright (1984), Richardson (1981)

Transition probabilities: Geng et al. (1986)

Future Climate Scenarios

Present: CRU climatology (1961–1990) (New et al., 2000)
2050's: 30-years climatology (2036–2065)

- RCP 3

Radiative Forcing peaks at 3.1 W/m^2 in 2050
Returns to 2.6 W/m^2 by 2100

- RCP 4.5

Radiative Forcing stabilized before 2100
(at 4.5 W/m^2)

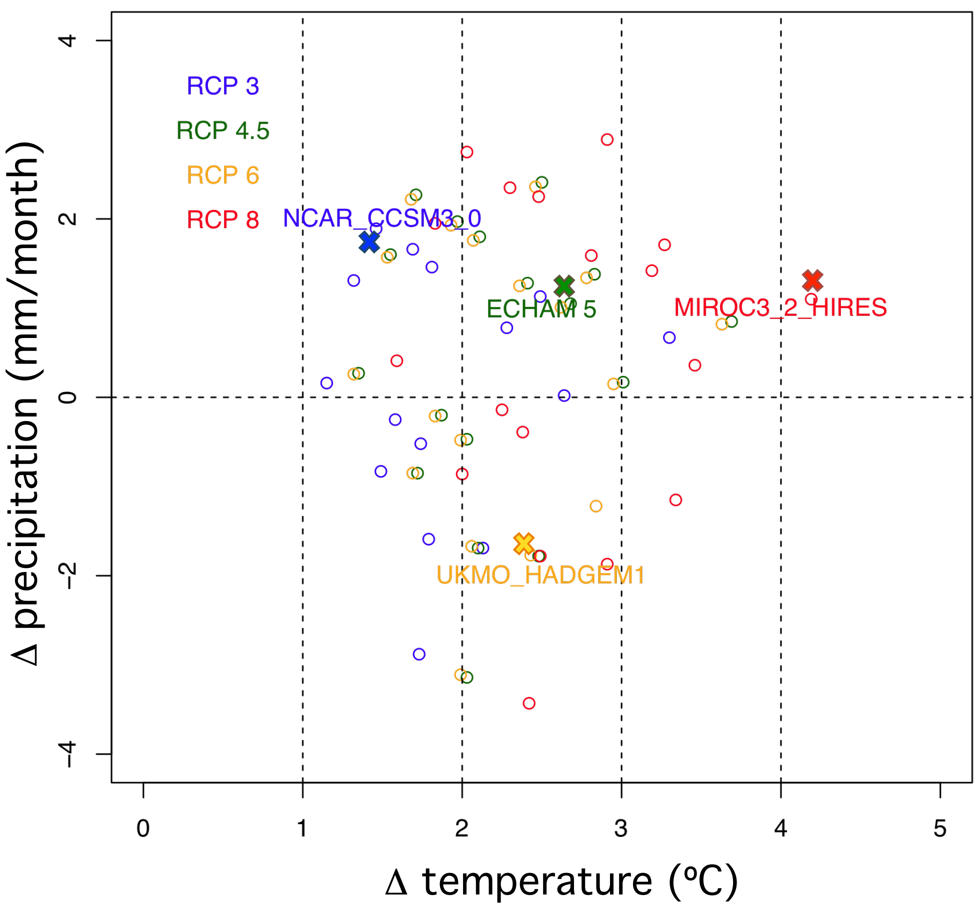
- RCP 6

Radiative Forcing stabilized after 2100
(at 6 W/m^2)

- RCP8

High emissions level (8 W/m^2 by 2100)
No stabilization

Mean relative change with present



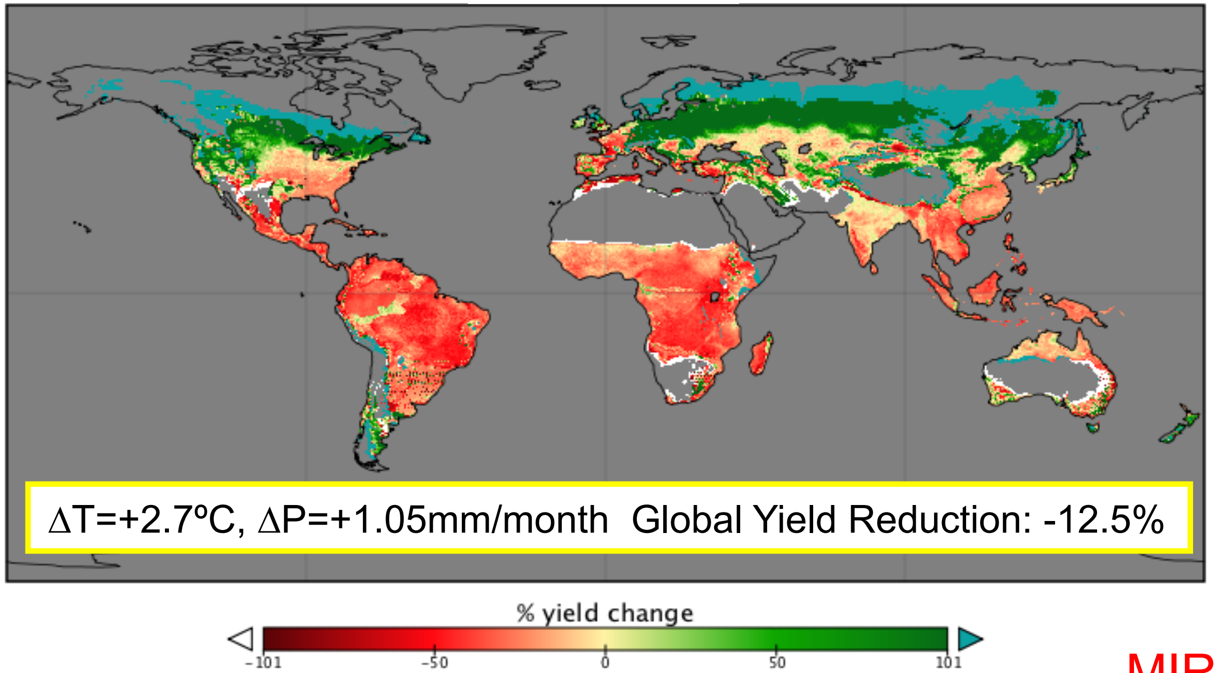
Preliminary Results

Relative change: 2036–2065 / 1961–1990

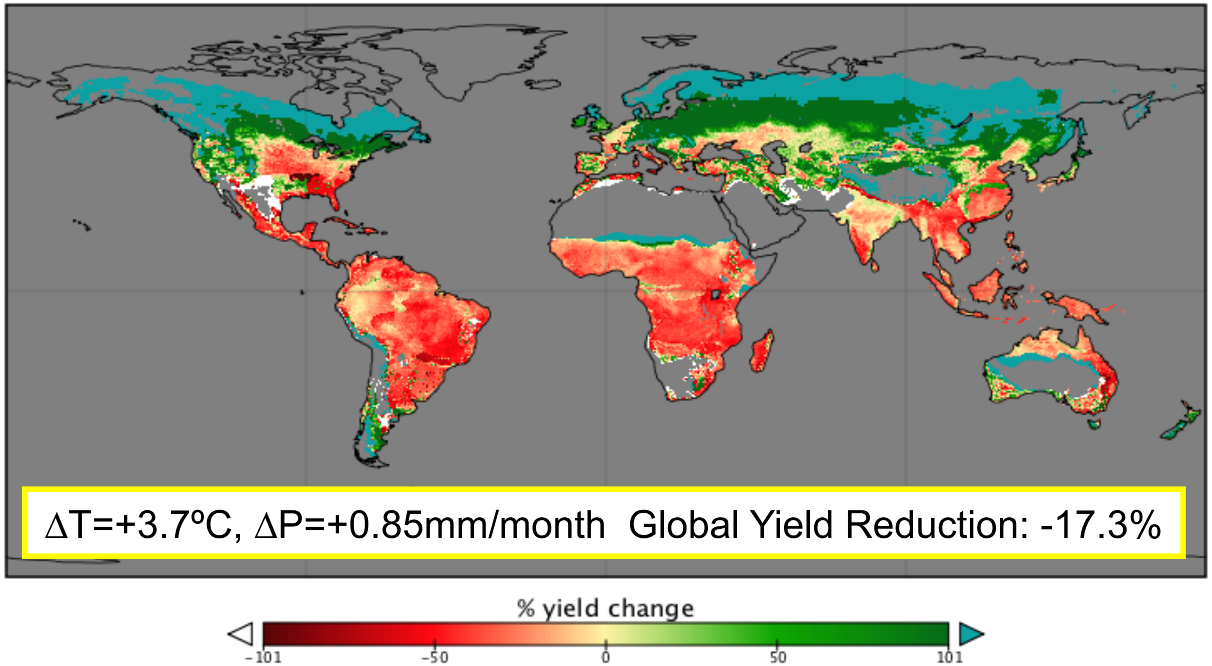
RCP	GCM	ΔT (ºC)	ΔP (mm/month)	ΔY (%)
RCP 3	NCAR_CCSM_3.0	+1.3	+1.31	-1.8
RCP 3	GFDL_CSM2_0	+1.8	-1.59	-6.4
RCP 6	GFDL_CSM2_0	+2.1	-1.67	-9.1
RCP 3	ECHAM 5	+2.3	+0.78	-9.2
RCP 4.5	GFDL_CSM2_0	+2.1	-1.69	-9.4
RCP 6	UKMMO_HADGEM1	+2.4	-1.77	-11.4
RCP 6	ECHAM 5	+2.6	+1.01	-12.1
RCP 4.5	ECHAM 5	+2.7	+1.05	-12.5
RCP 8	GFDL_CSM2_0	+2.5	-1.78	-13
RCP 8	ECHAM 5	+3.2	+1.42	-16.1
RCP 8	MIROC3.2_HIRES	+3.7	+0.85	-17.3

Regional differences ECHAM 5 MIROC 3.2_HIRES for RCP 8

ECHAM 5

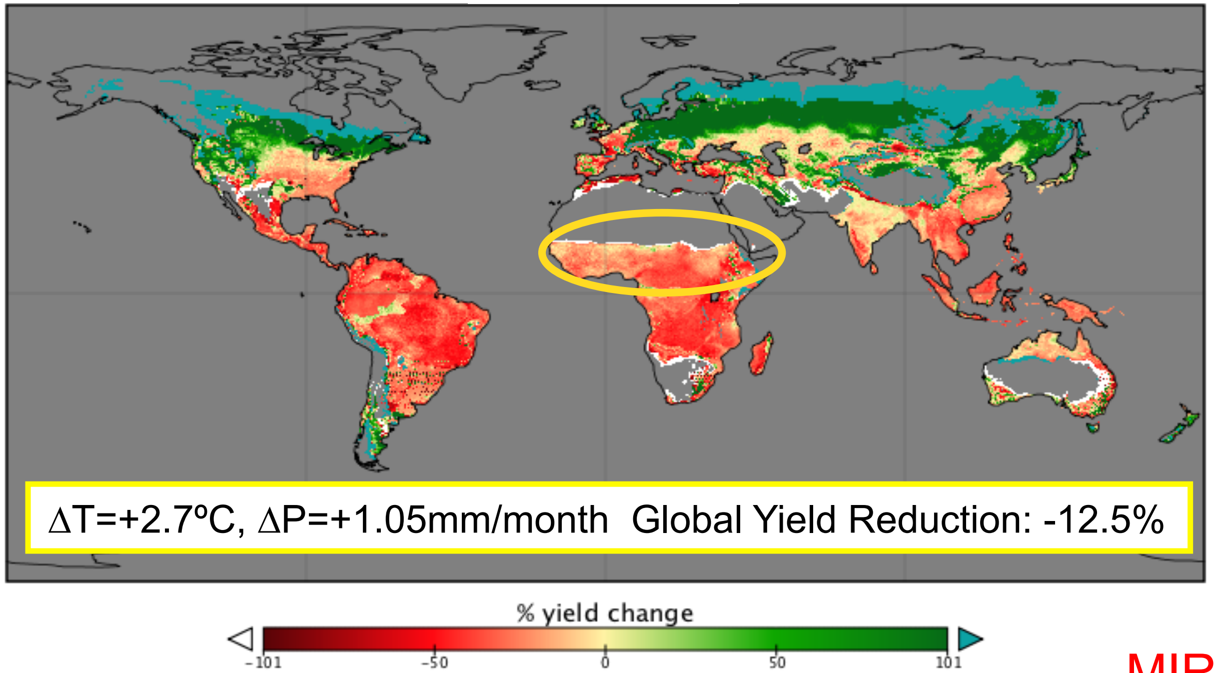


MIROC 3.2_HIRES

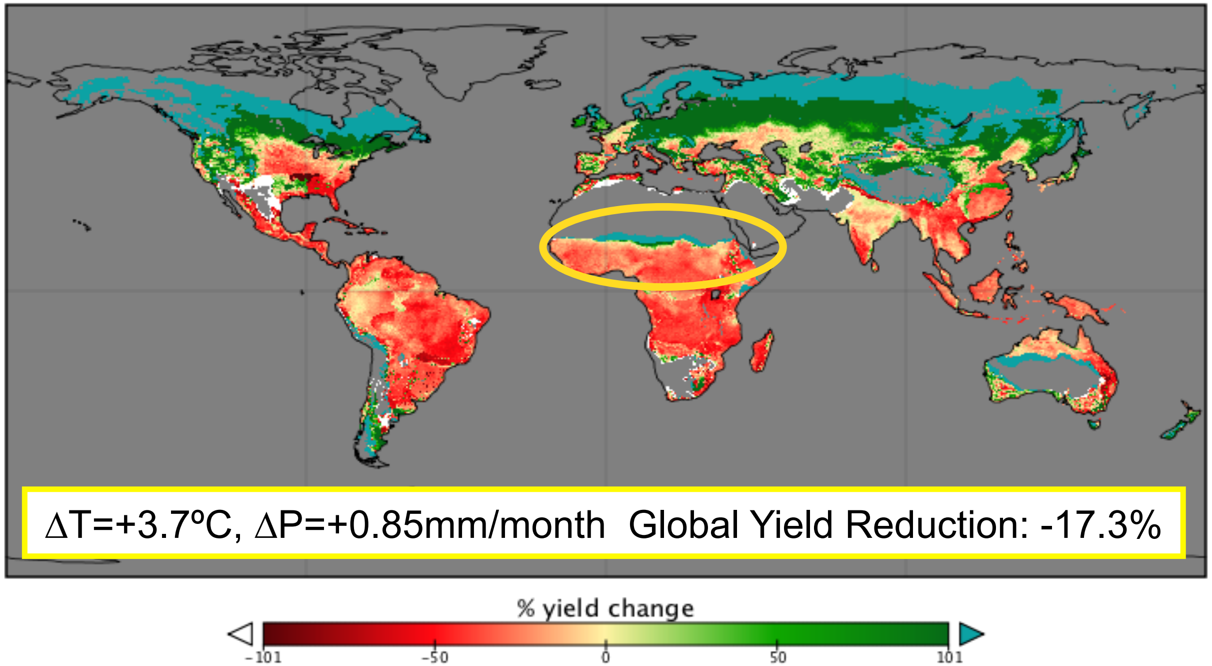


Regional differences
ECHAM 5
MIRROC 3.2_HIRES
for RCP 8

ECHAM 5

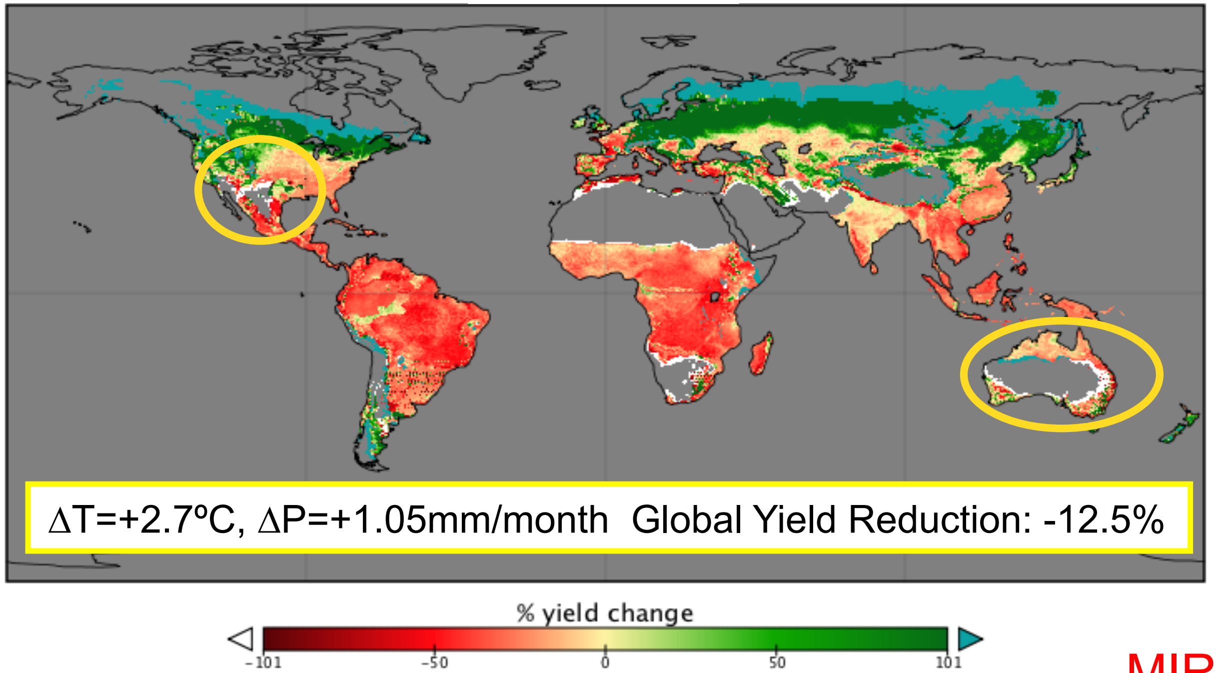


MIROC 3.2_HIRES



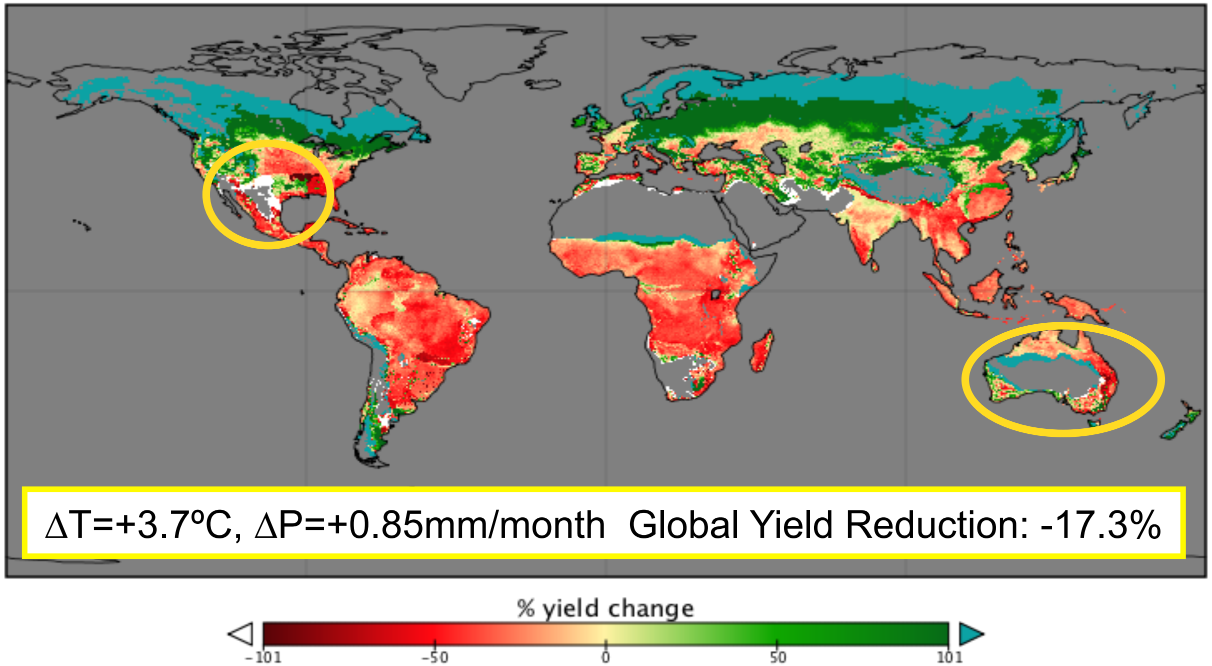
Tyndall°Centre® for Climate Change Research

ECHAM 5



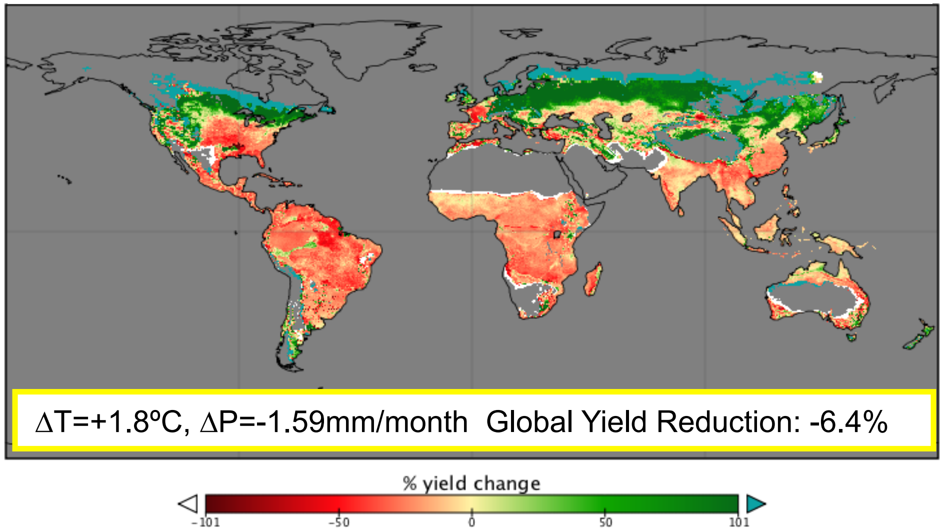
Regional differences
ECHAM 5
MIROC 3.2_HIRES
for RCP 8

MIROC 3.2_HIRES

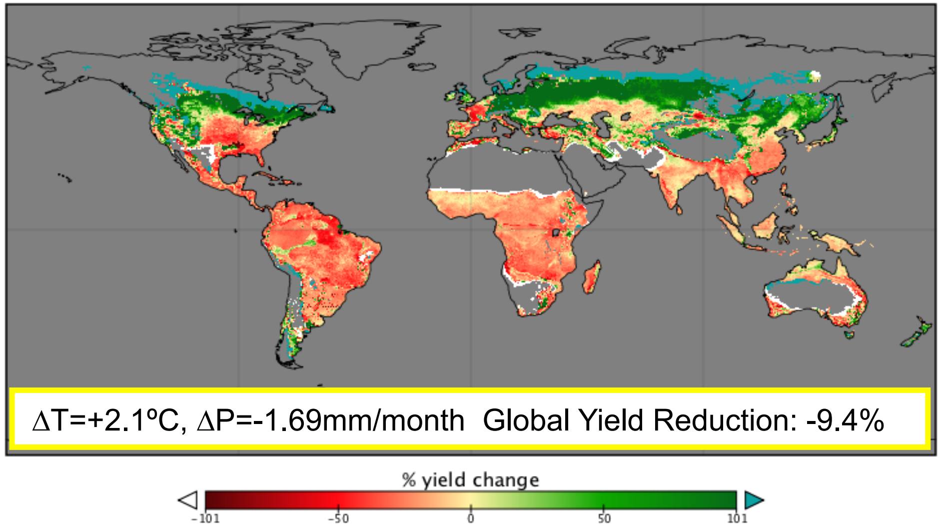


WCRP Tyndall°Centre® for Climate Change Research UEA University of East Anglia

RCP 3

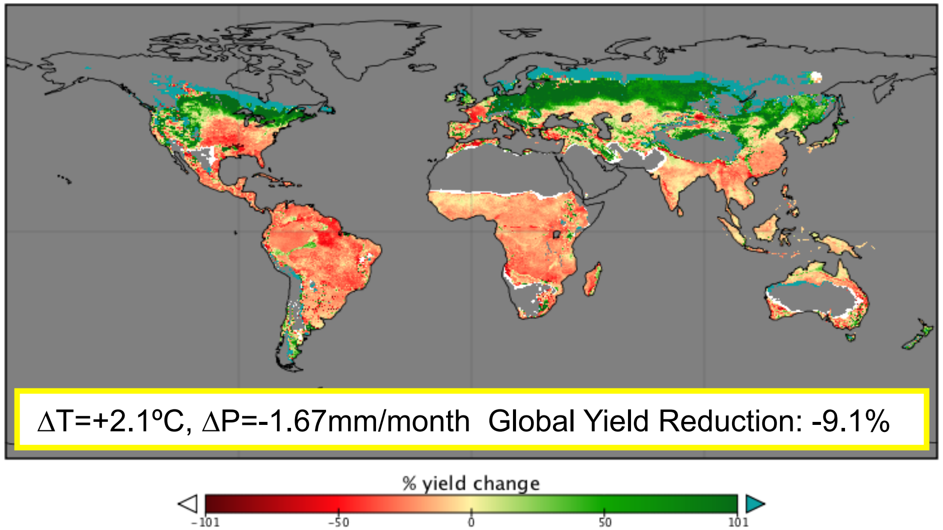


RCP 4.5

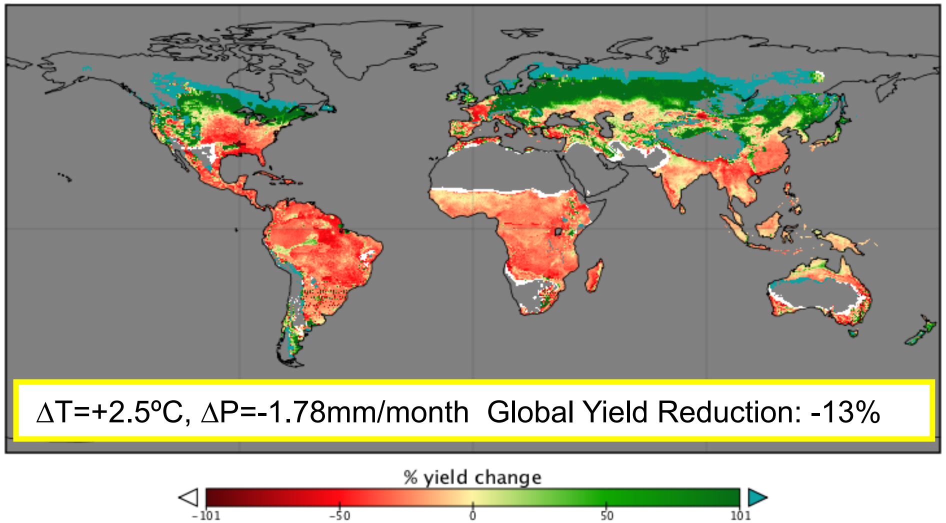


GFDL_CSM2_0

RCP 6

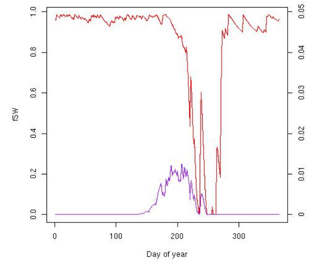


RCP 8



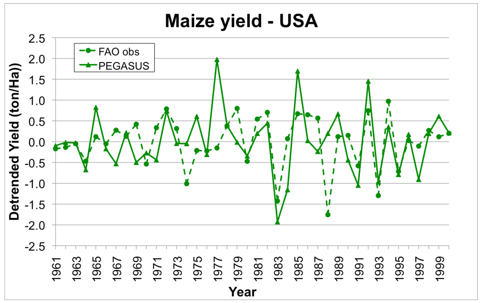
SUMMARY

Effect of climate variability on global crop yield for Maize
Analysis at different spatio-temporal scales:



1. Daily variability at the grid-cell level:

→ Biomass production is highly sensitivity to droughts on a daily time-step



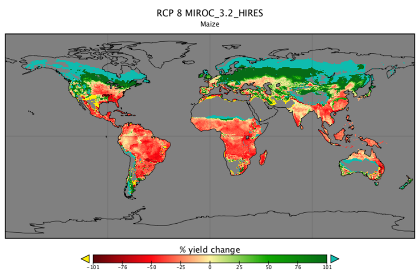
2. Inter-annual variability at the regional scale:

→ Model results show higher variability than observation

→ Model very sensitive when adapting to droughts with irrigation

→ Planting dates decisions or choice of crop cultivars depend on mean climate (not very sensitive to climate variability)

3. 30-years climatology at the global scale:



→ Significant impact by 2050's even with adaptation (-2% to -17% decrease in maize yield globally)

→ Global scale levels out variability in the results

→ Global average strongly correlated to global increase in temperature

→ Impact of droughts better described regionally

CONCLUSION

- Agricultural productivity is vulnerable to droughts
- PEGASUS simulates the effect of water stress on daily biomass production
- Challenges at the global scale in distinguishing between impacts of:
    1. changes in mean climate
    2. changes in climate variability
- Large uncertainties in crop yield simulations for the future reflect large uncertainties in future precipitation patterns among GCMs

NEXT...

- Exploring further model inter-annual variability of crop yield at the regional scale (using historical and future climate data)
- Identifying **heat stress** versus **water stress** extreme events and their respective effects on biomass production in PEGASUS
- Running PEGASUS with all combinations of RCPs/GCMs scenarios
- Exploring regional precipitation variability and estimated crop yields
- Exploring the effect of agricultural adaptation options (mainly irrigation within PEGASUS)
- Including **soybean** and **spring wheat** in the analysis

Thank You!

Deryng, D. and R. Warren (in prep.)
Deryng, D., W. J. Sacks, C. C. Barford, and N. Ramankutty (2011), Simulating the effects of climate and agricultural management practices on global crop yield, Global Biogeochem. Cycles, 25, GB2006, doi:10.1029/2009GB003765

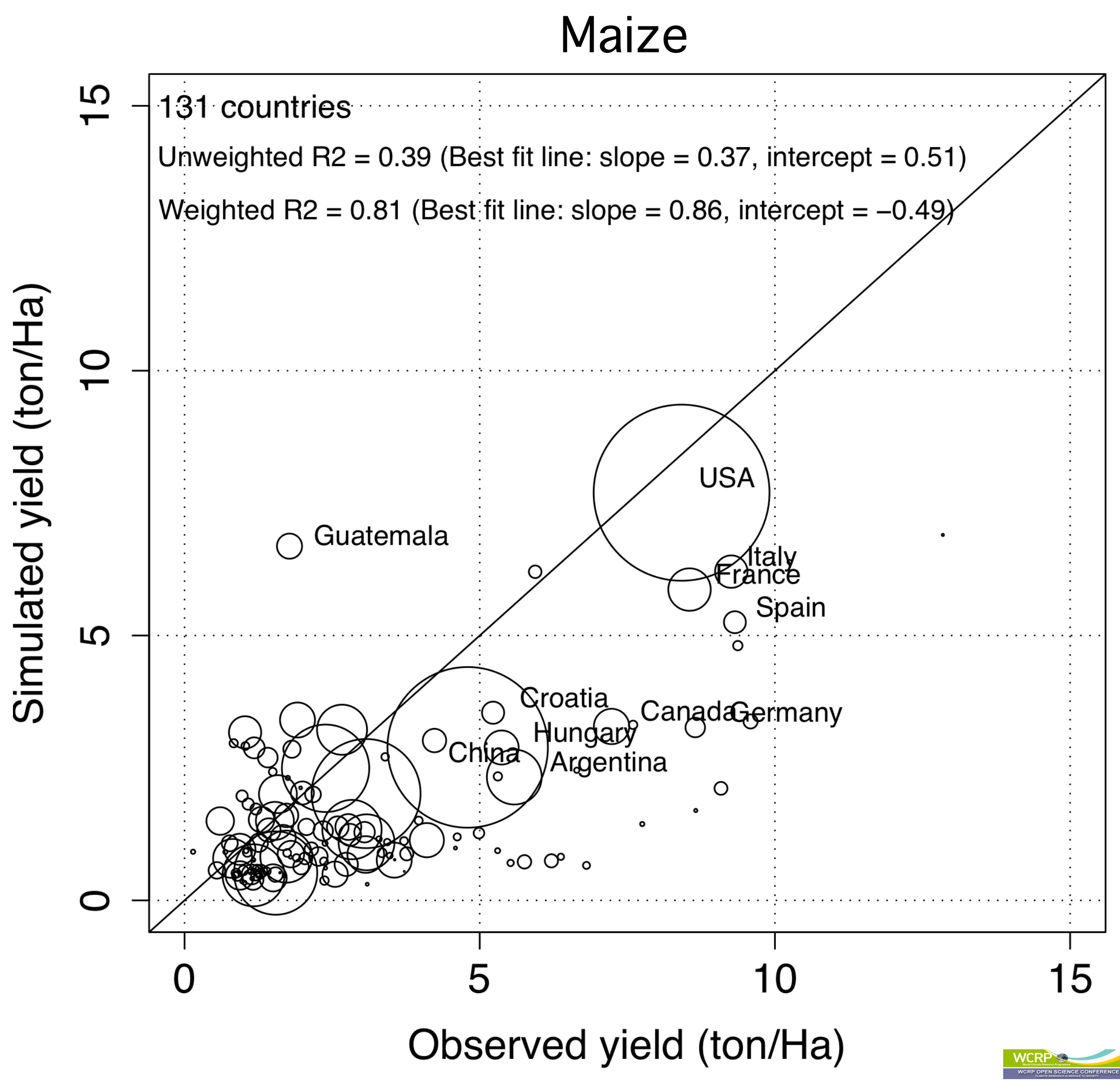
d.deryng@uea.ac.uk

d.deryng@uea.ac.uk

References

- **Deryng, D. and R. Warren (in prep.)**, Evaluating the impact and risk associated with more frequent and stronger extreme climate events on global crop yield.
- **Deryng, D. et al. (2011)**, Simulating the effects of climate and agricultural management practices on global crop yield, Global Biogeochem. Cycles, 25, GB2006, doi:10.1029/2009GB003765.
- **Geng, S. (1986)**, A simple method for generating daily rainfall data, Agricultural and Forest Meteorology, 36(4), 363–376, doi:10.1016/0168-1923(86)90014-6.
- **Gornall, J. et al. (2010)**, Implications of climate change for agricultural productivity in the early twenty-first century, Phil. Trans. R. Soc. B, 365(1554), 2973–2989, doi:10.1098/rstb.2010.0158.
- **Moss, R. H. et al. (2010)**, The next generation of scenarios for climate change research and assessment, Nature, 463(7282), 747, doi:doi:10.1038/nature08823.
- **Nelson, G. C. et al. (2009)**, Climate change: Impact on agriculture and costs of adaptation, International Food Policy Research Institute (IFPRI).
- **Ngo-Duc, T., and J. Polcher (2005)**, A 53-year forcing data set for land surface models, JGR.
- **Parlange, M., and R. W. Katz (2000)**, An extended version of the Richardson model for simulating daily weather variables, J Appl Meteorol, 39.
- **Parry, M. et al. (2005)**, Climate change, global food supply and risk of hunger, Phil. Trans. R. Soc. B, B(360), 2125–2138.
- **Richardson, C. W. (1981)**, Stochastic simulation of daily precipitation, temperature, and solar radiation, Water Resources Research, 17(1), 182–190, doi:10.1029/WR017i001p00182.
- **Richardson, C. W., and D. A. Wright (1984)**, WGEN: A model for generating daily weather variables. USDA Publication ARS-8, 83 pp. [Available from National Technical Information Center, 5285 Port Royal Rd., Springfield, VA 22161.]
- **Warren, R. et al. (2009)**, The Community Integrated Assessment System CIAS, a new approach to distributed integrated modelling, IOP Conference Series: Earth and Environmental Science, 6(49), 492013, doi:10.1088/1755- 1307/6/9/492013.

Comparison of simulated crop yields and corresponding observations



Tyndall°Centre® for Climate Change Research