The Abdus Salam International Centre for Theoretical Physics

United Nations Educational, Scientific and Cultural Organization

IAEA International Atomic Energy Agency

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Joint ICTP-IAEA Conference on Coping with Climate Change and Variability in Agriculture through Minimizing Soil Evaporation Wastage and Enhancing More Crops per Drop

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Assessment of crop water requirement through GLAM modelling

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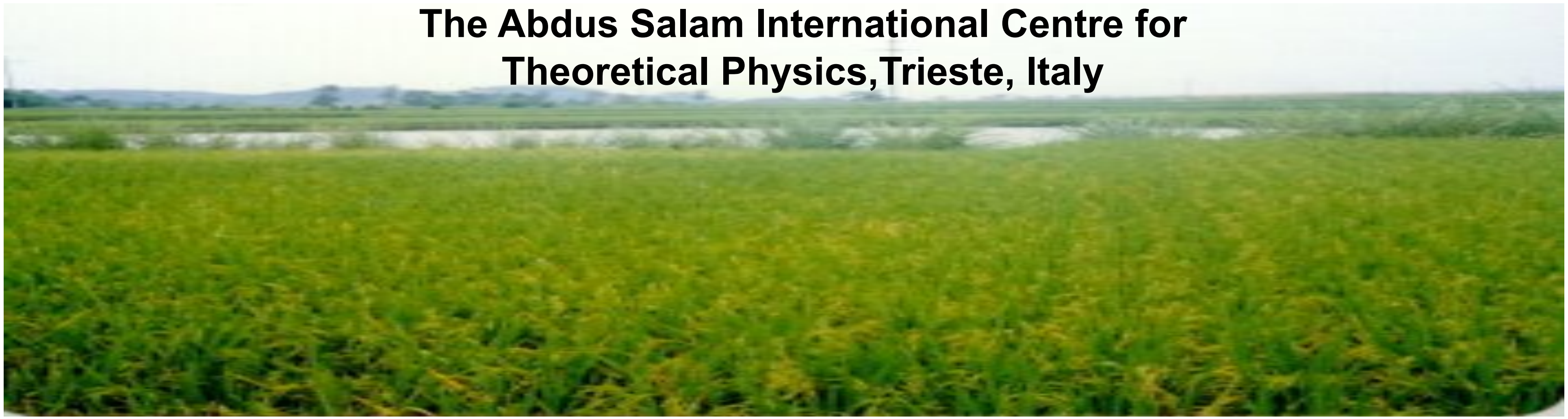


Outline

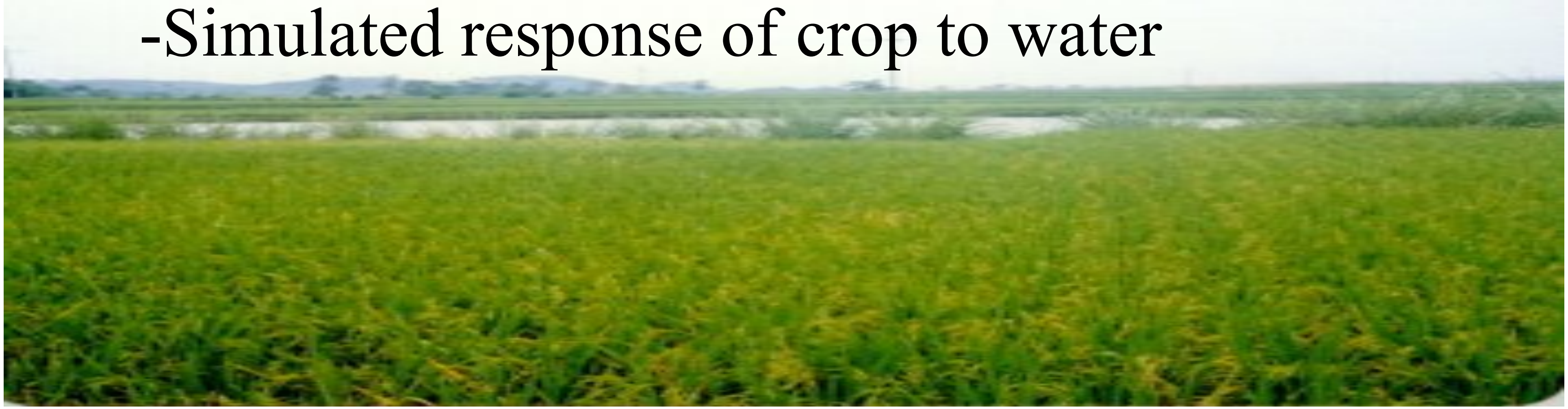
- **Climate and agriculture**
- Introduce the crop models

  -Crop biomass accumulation model

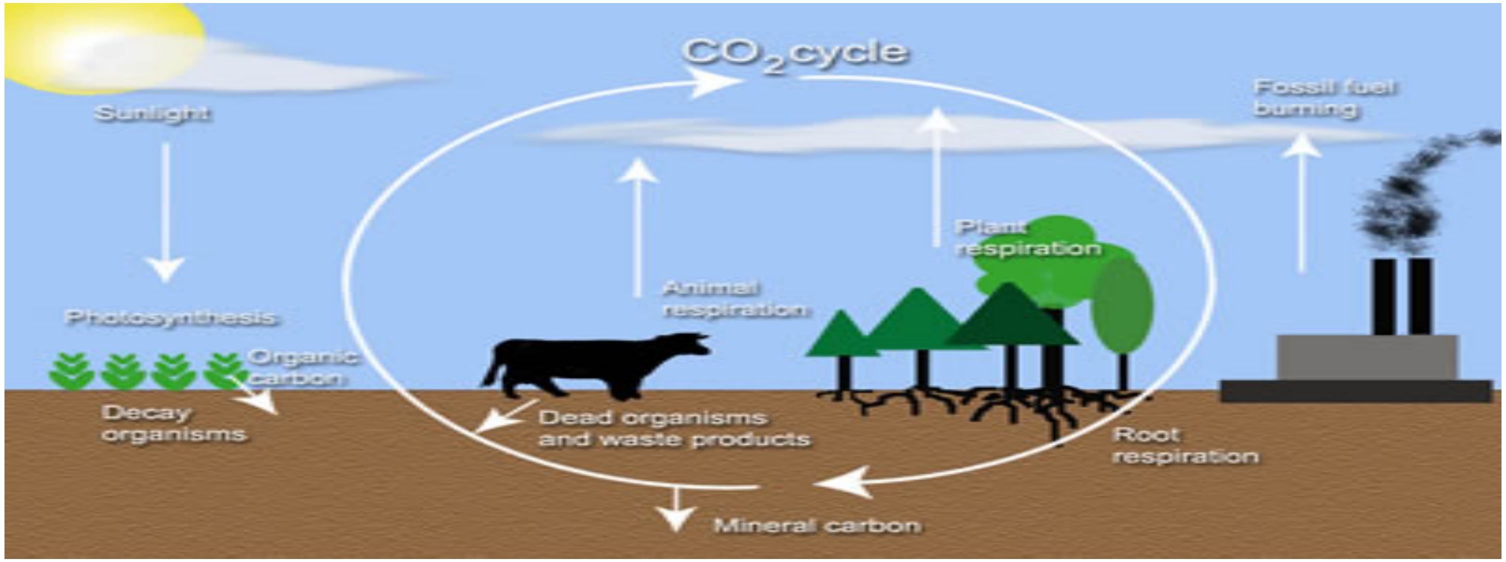
  -Water balance model
- The response of crop to water

  -Observed response of crop to water

  -Simulated response of crop to water



Climate and Agricultural productivity



- **Climates factors directly affect agricultural productivity:**

-temperature

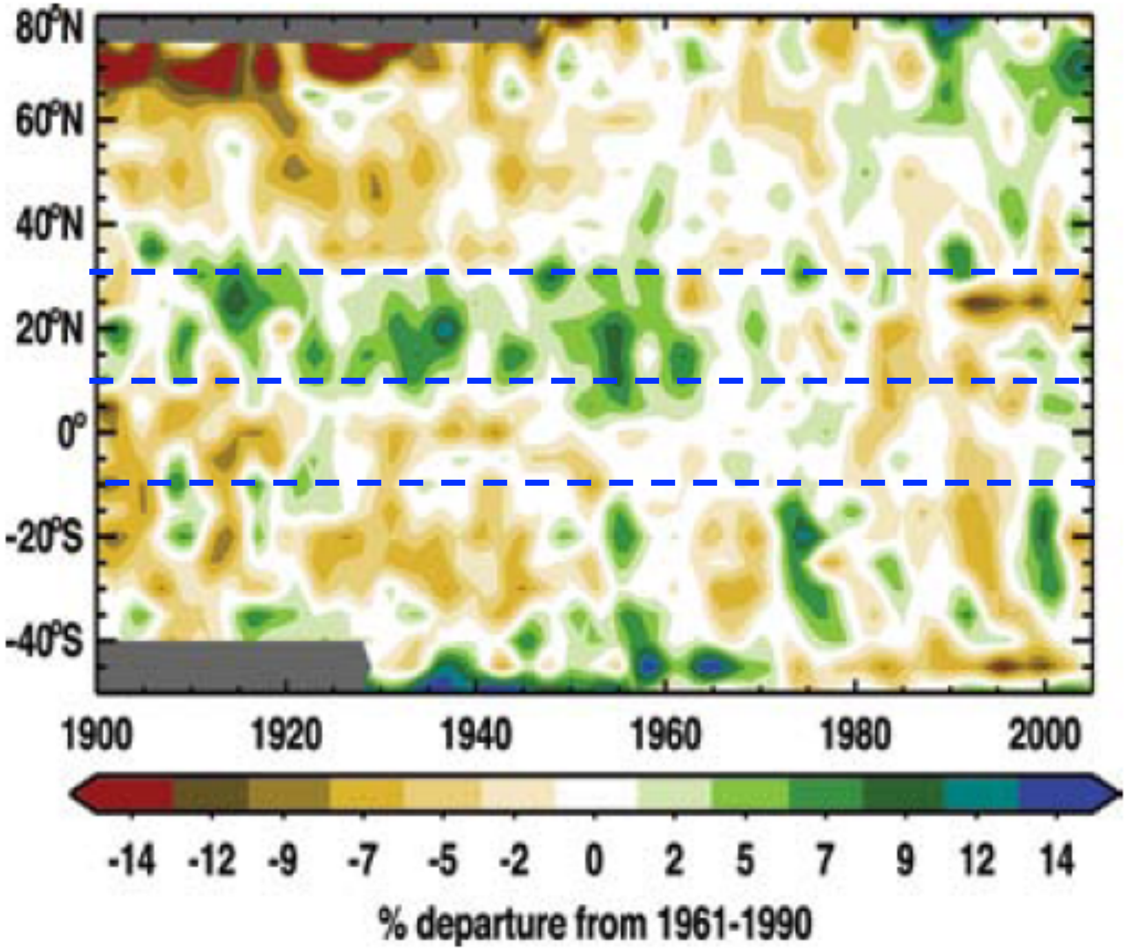
-rainfall amount and patterns

-solar radiation

-atmospheric [CO2]

-climatic variability and extreme events

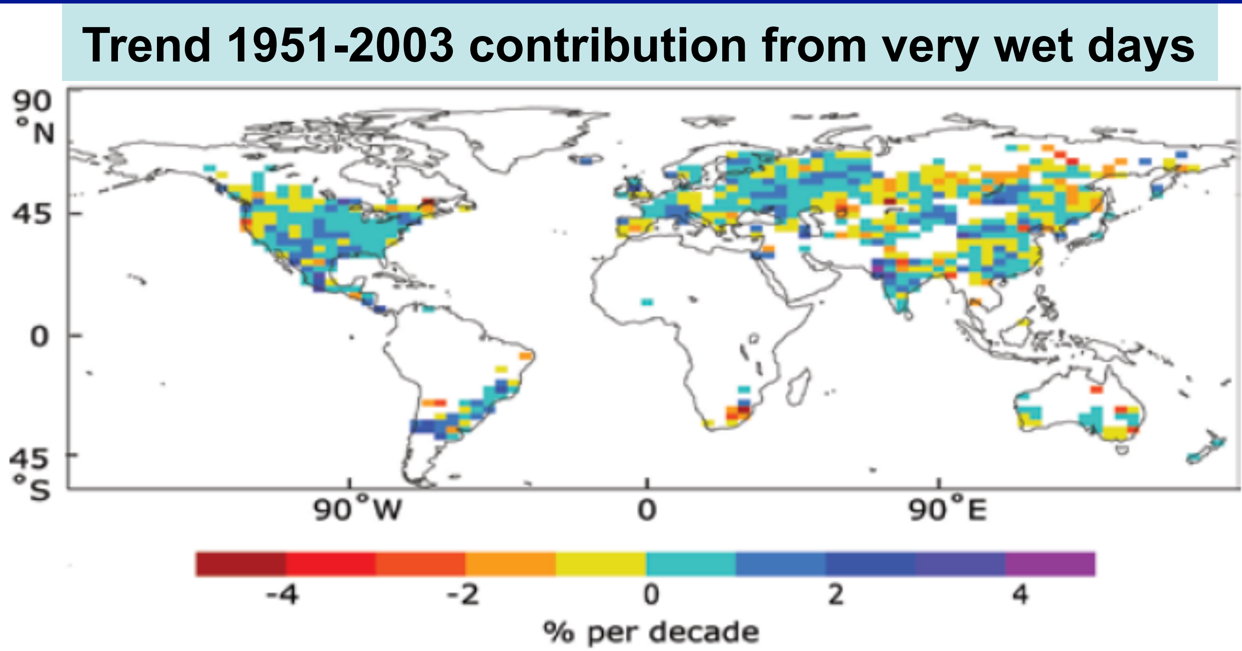
Precipitation over land: past trend

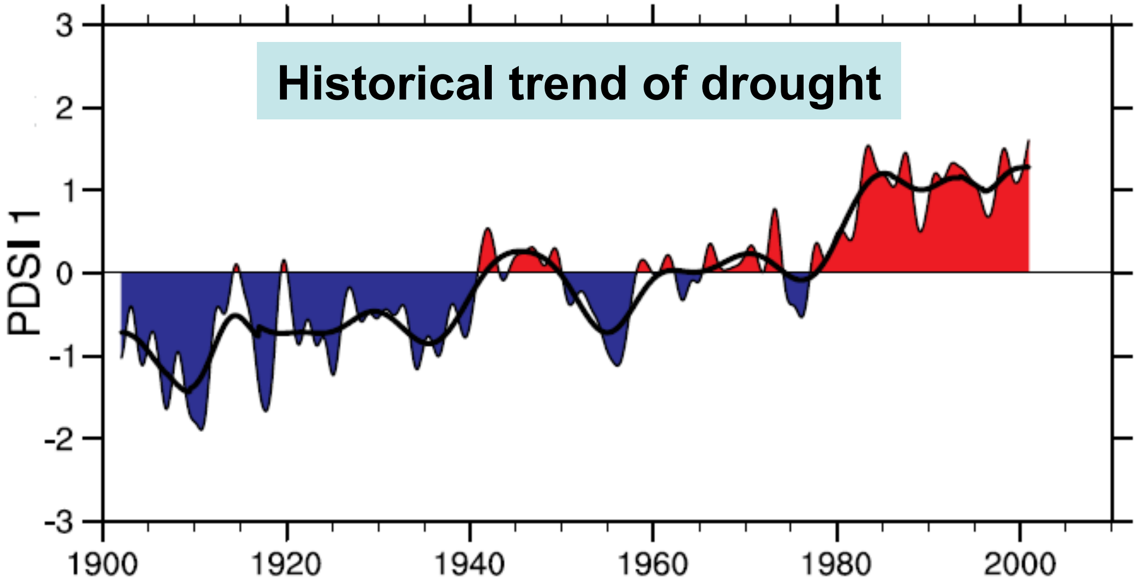


- **30°N ~ 85°N**
  increase in 20th century
- **10°S ~ 30°N**
  notable decrease in the past 30–40 years
- **10°N to 30°N**
  increase markedly from 1900 to 1950s; decline after about 1970
- **Southern hemisphere**
  No strong trends

Latitude–time section of average annual anomalies for precipitation (%) over land from 1900 to 2005, relative to their 1961–1990 means.

Precipitation patterns have changed





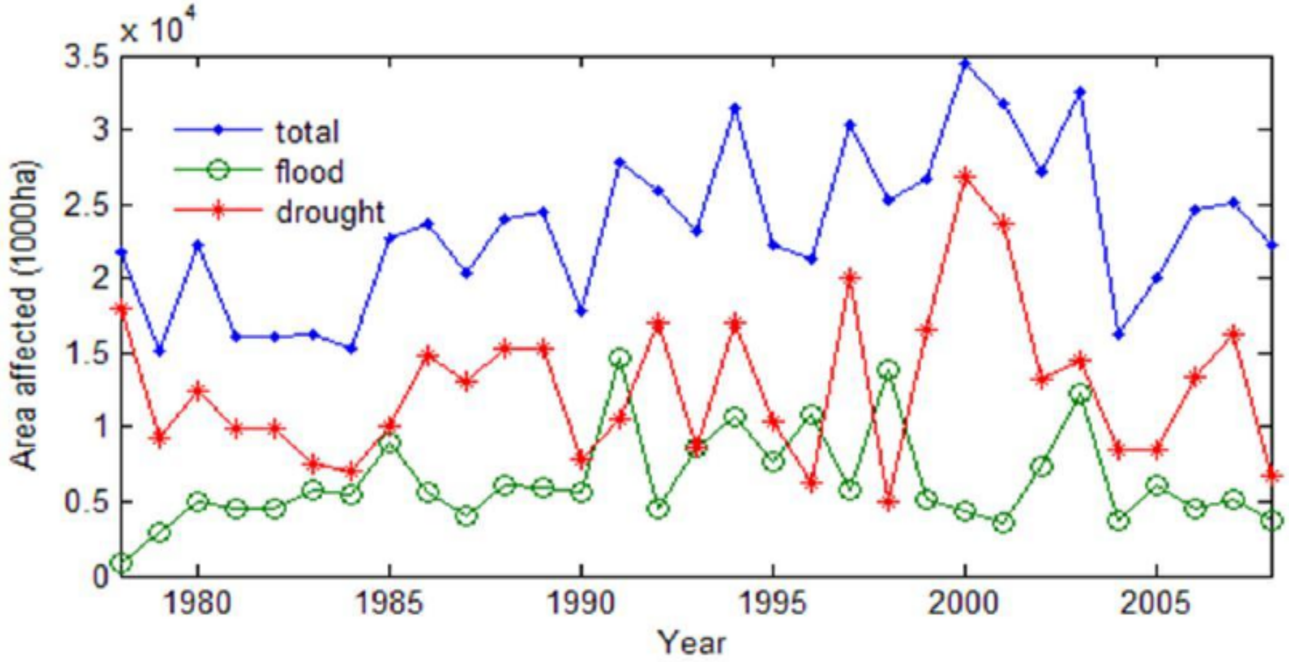
Increase in frequency of **heavy precipitation events**

Increase in **drought events**

Extreme rainfall and agriculture productivity

- Increase in extreme climate event such as floods and droughts can affects crop yield stability, consequently, increases the risks to yield
- affect agricultural productivity, food supply and food security

The area of cropland affected by droughts and floods in China



the economic losses in agriculture due to drought and floods from 1998 to 2004 are 75. 69 billion RMB/a and 51.16 billion RMB/a, respectively, and which account for 1.2% and 0.8% of China's GDP.

Important of Rainfall

- Arid and semi-arid areas account for about 40% the land surface of the world, especially some African countries, where rain-fed agriculture is already limited by water availability (Gamo, 1999).
- Understanding how crop response to water will help the development of the monitoring and prediction tools to help planners and farmers reduce negative impacts or use the favourable climate

Sufficient Rainfall – Good Crop

Low Rainfall – Poor Crop

Climate and Agriculture

Understand the plants, soil, weather and management interactions

- Studies of the effect of weather and climate on agriculture are often limited by the availability of climatological data and experimental results.
- The interactions between the plant and its environment cannot be reflected by the simple crop-climate regression
- Crop models provide useful tools for analysing crop and its relationship with the climate.

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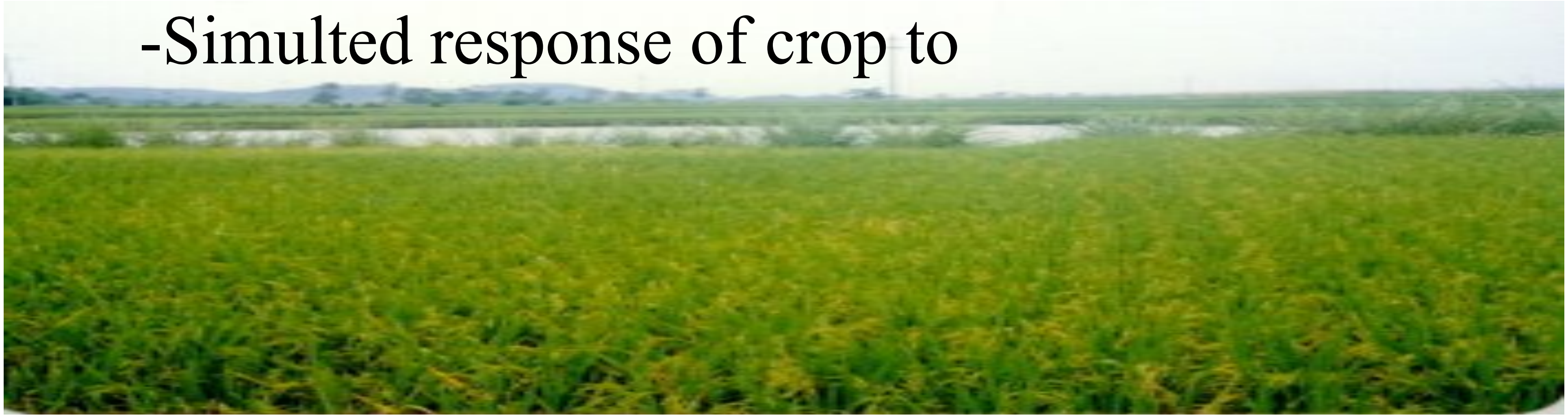


Crop simulation models

- Site based crop models:

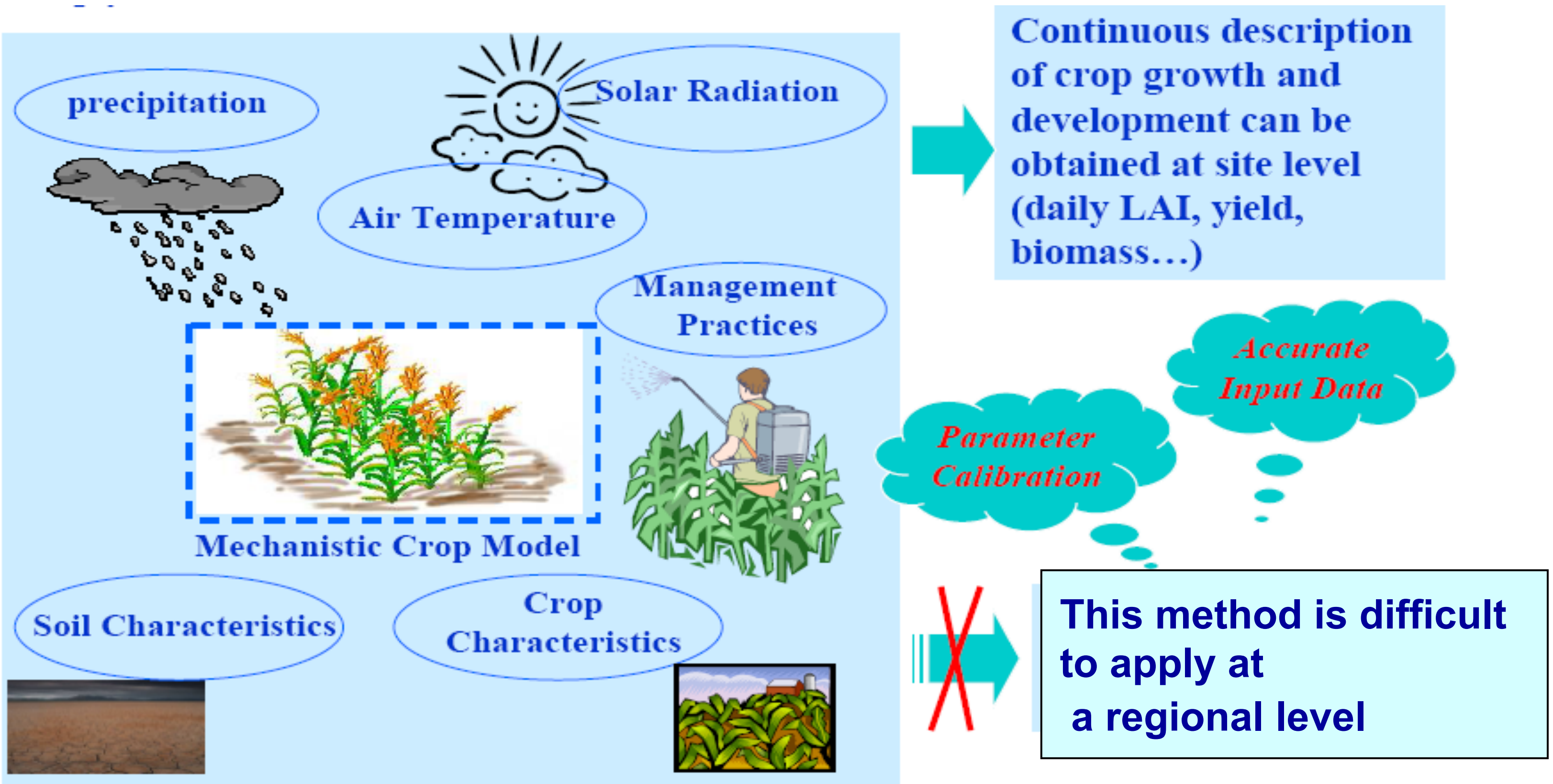
  Seek to simulate the complex dynamics of crop growth and development, and its response to environmental variables

- Large area crop mode (e.g. GLAM):

  Applied some simple assumptions and empirical relationships to predict the complex crop growth and development

Crop model at the field level

- High input data requirement
- Complexity of incorporating the spatial variability of input
- Climate model output is coarse compared with input to crop model

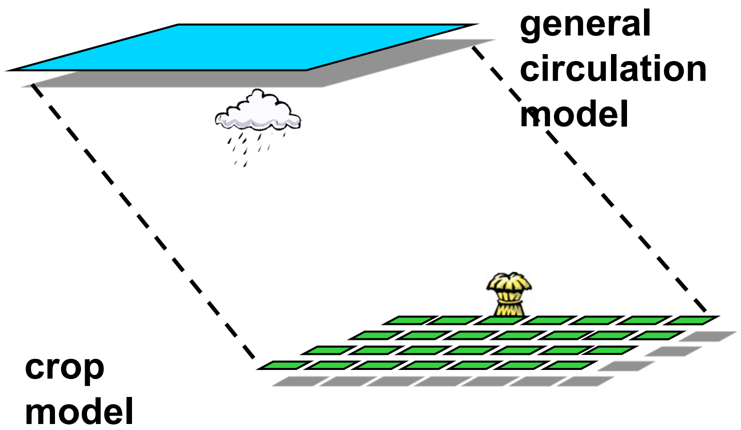


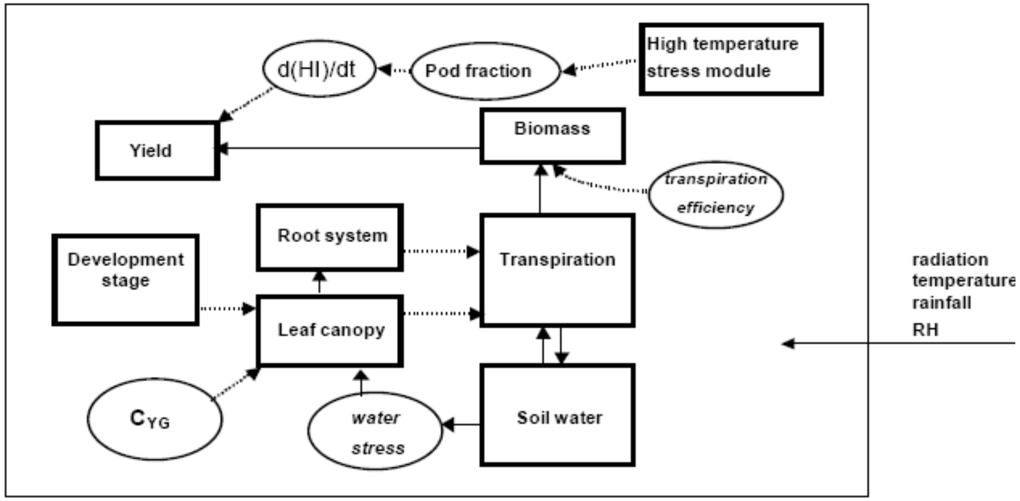
(Yang.P).

General Large Area Model for annual crops (GLAM; Challinor *et al*, 2004)

- Aims to combine:
  - the benefits of more empirical approaches (low input data requirements, validity over large spatial scales) ***with***
  - the benefits of capturing intra-seasonal variability, and so cope with changing climates)

- Field management -Yield Gap Parameter





Crop model-Input and output

Input

Daily weather

-Rainfall

-Tmax

-Tmin

-Solar radiation

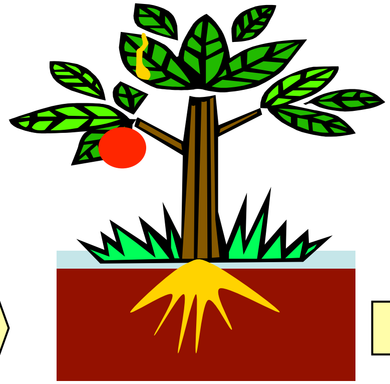
parameters

-soil physics,

-crop varieties

-phenology,

-agrononomy,

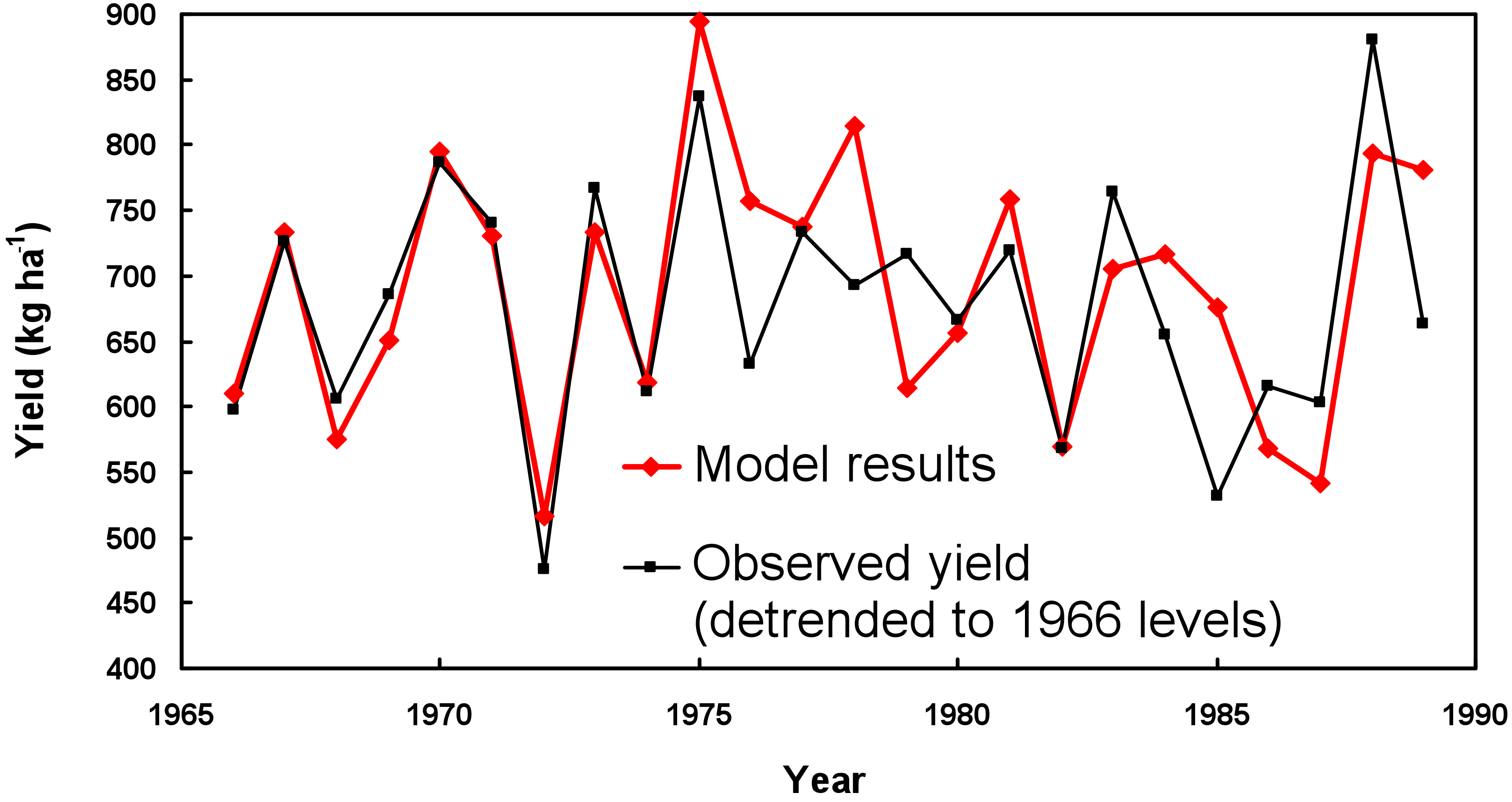


Crop model

Output

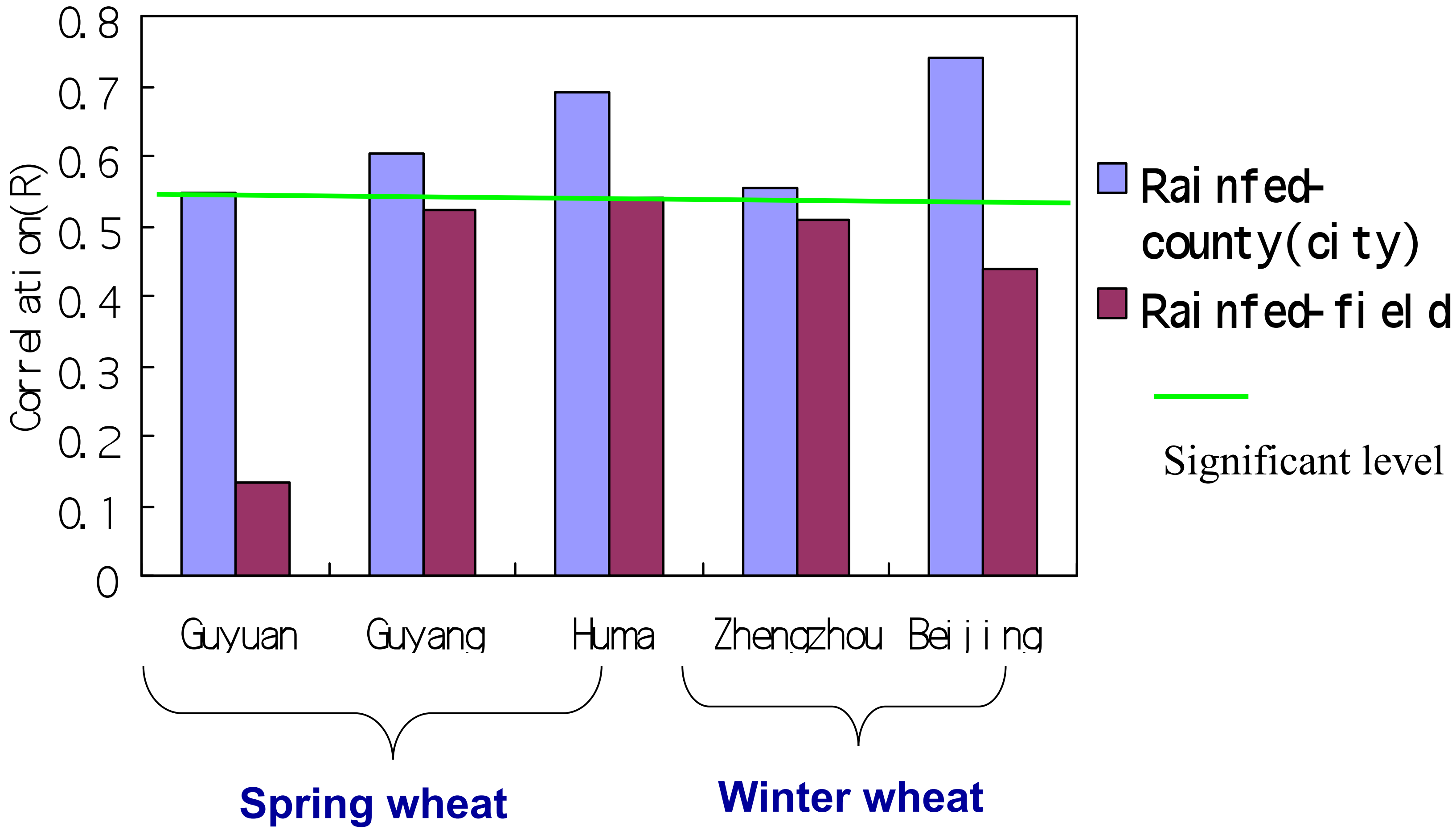
- Ø **Soil water balance**
- Ø **Leaf canopy**
- Ø **Root growth**
- Ø **Biomass**
- Ø **Yield production**

Validation of GLAM-groundnut model in Indian



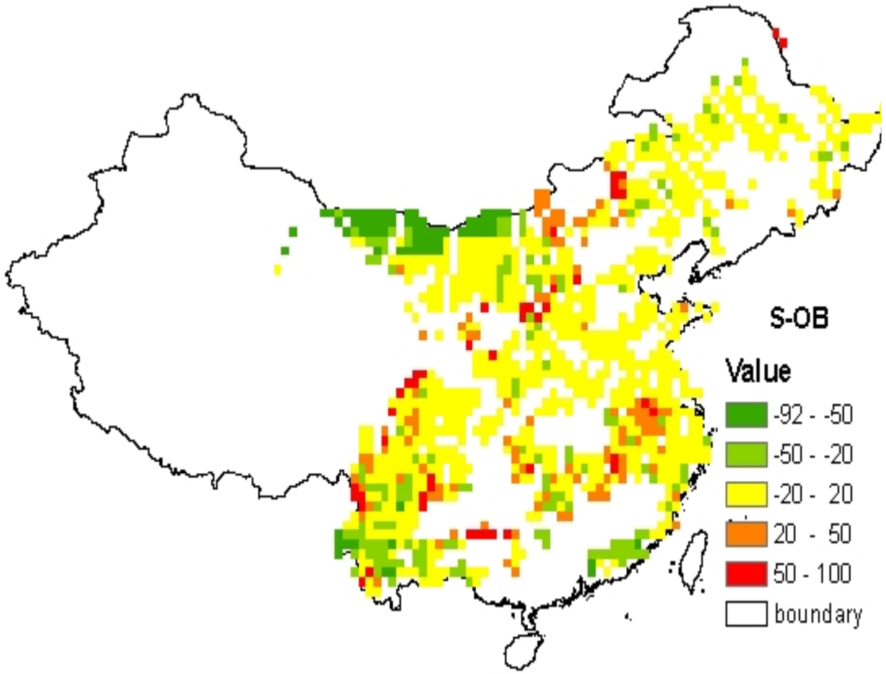
Challinor et al. 2004

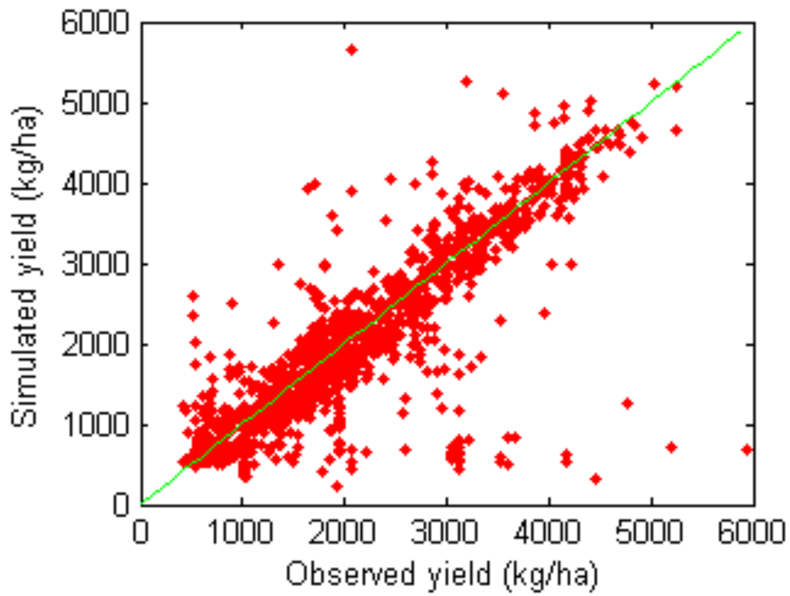
Correlation between observed and simulated yield at county(70-129km)/city(80-128km) level and field level in China



Validation of GLAM-Wheat in China

-Difference between observed and simulated mean wheat yield (%) in China (correlation r= 0.83,p<0.001)





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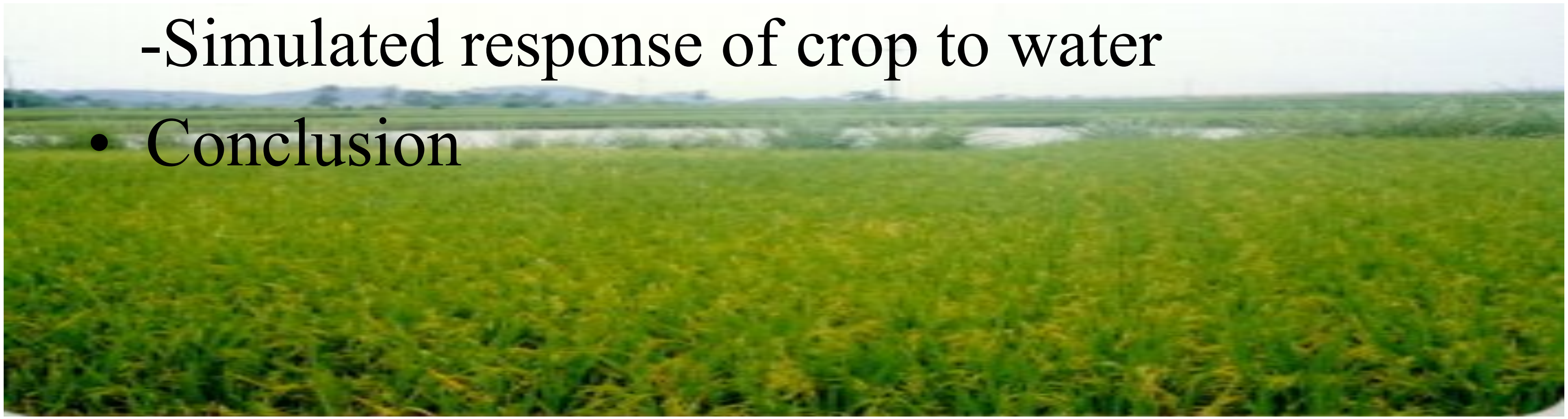
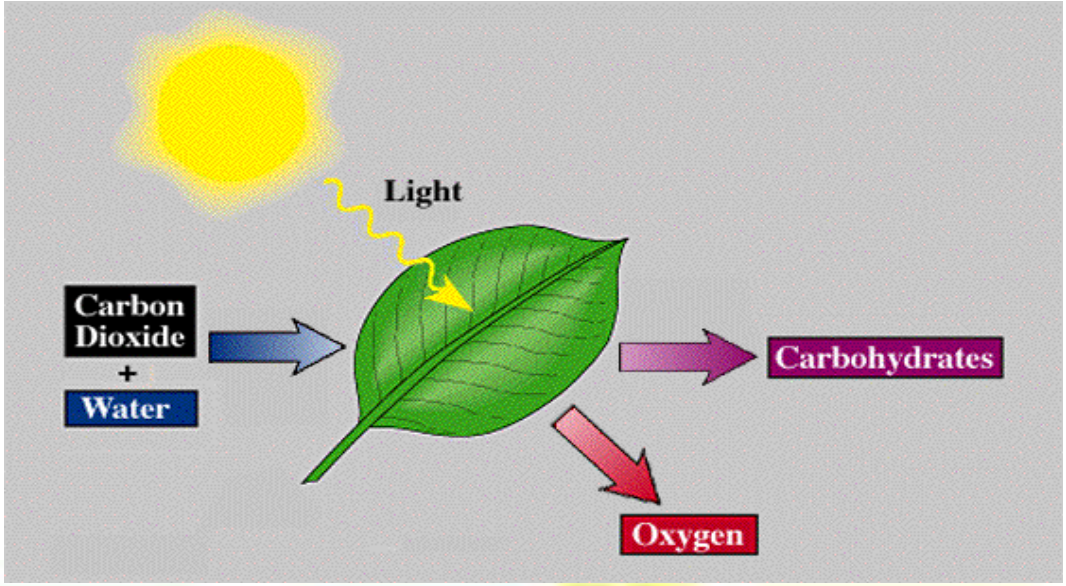
- Conclusion



Modelling growth: photosynthesis

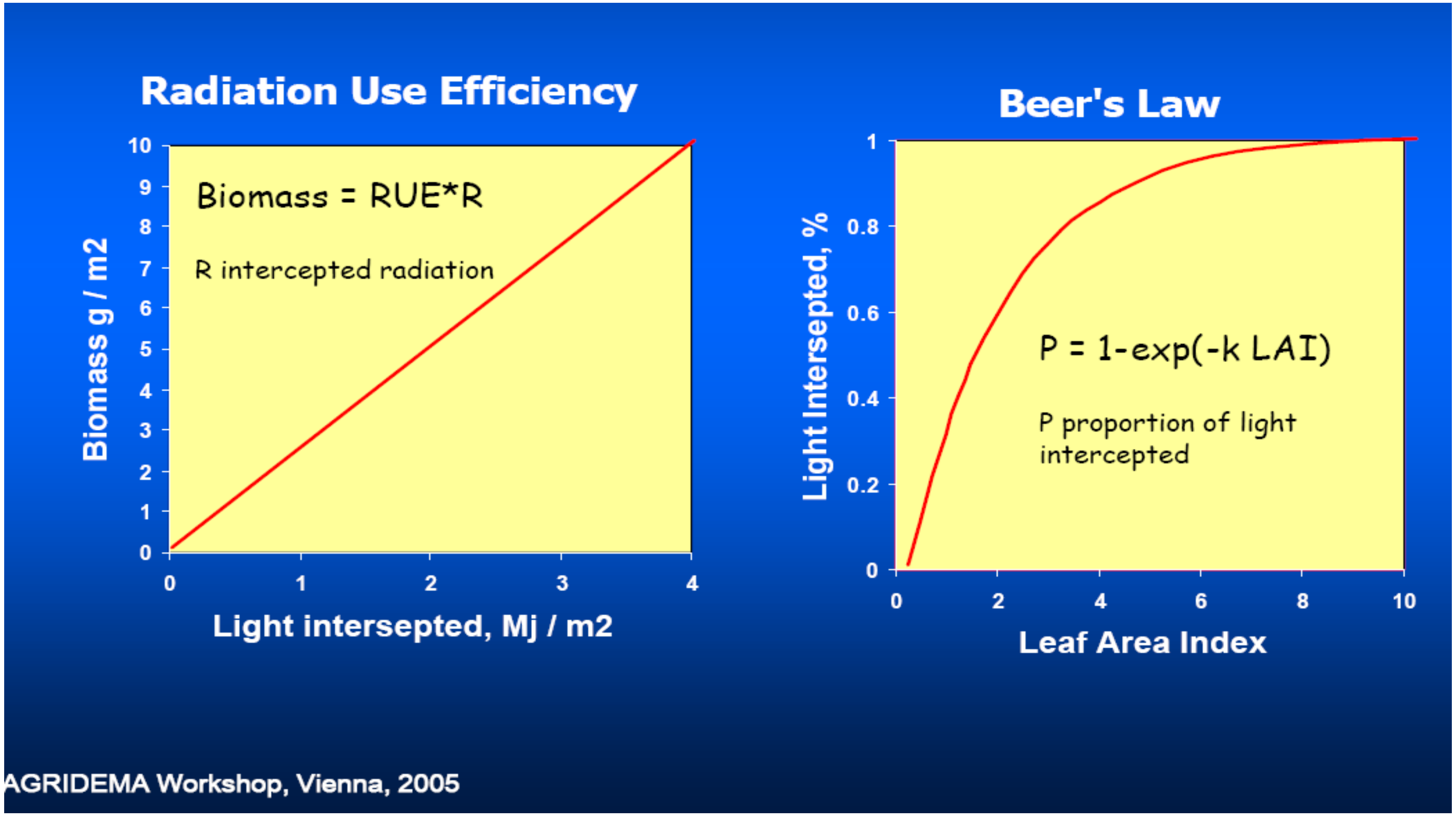
Photosynthesis: A chemical process by which a plant turns light energy from the sun into chemical energy in the form of sugar.



$$6\,CO_2 + 6\,H_2O \underset{\text{cellulose}}{\overset{\text{light}}{\rightleftharpoons}} C_6H_{12}O_6 + 6\,O_2$$

CarbonDioxide + Water → Sugar + Oxygen

Modelling crop growth: biomass



Modelling growth: biomass

- Biomass=RUE* intercepted solar radiation
- RUE normally increase with more N
- RUE decreased by significant stress eg. water

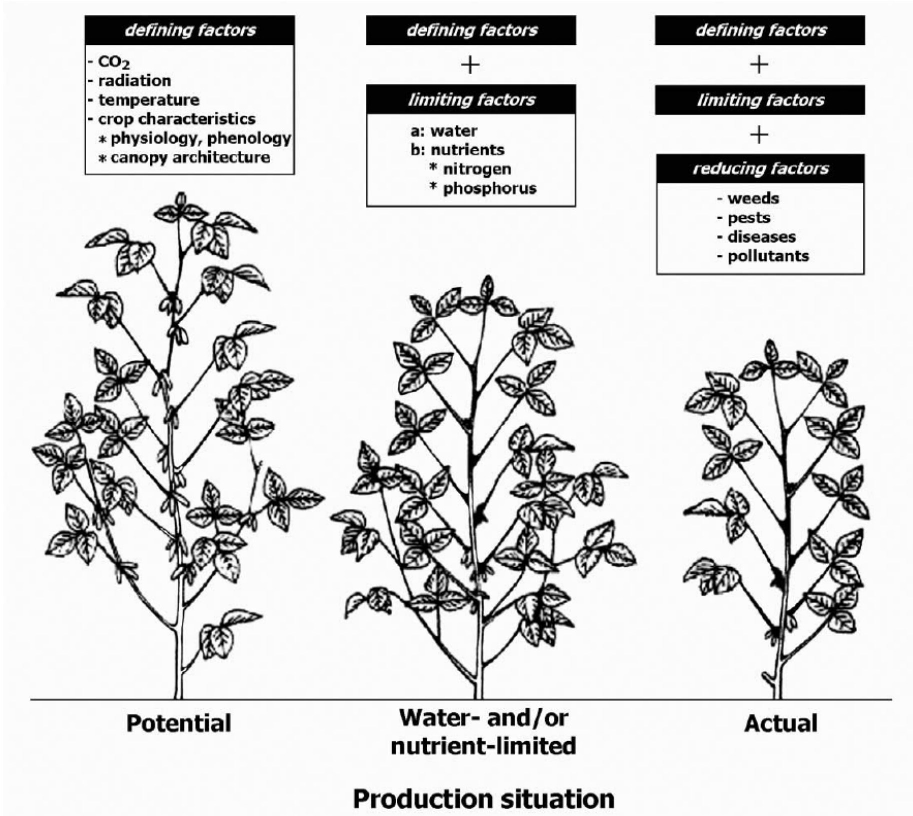
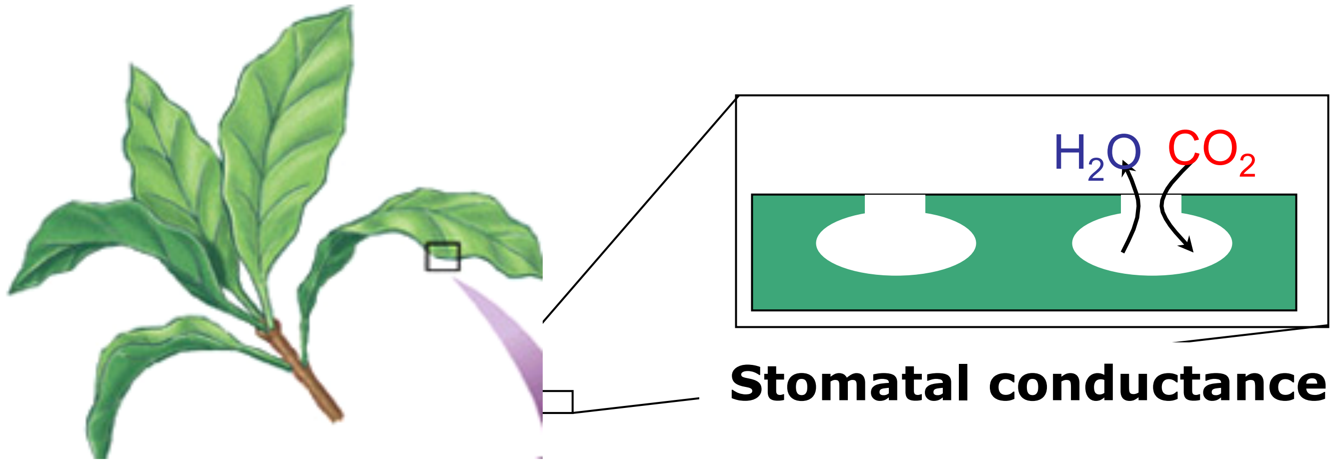


Fig. 1. A hierarchy of growth factors, production situations and associated production levels.

van Ittersum,2003

Modelling crop growth: biomass in GLAM



above ground biomass

transpiration efficiency

$$\frac{\partial W}{\partial t} = T_T \min\left(\frac{E_T}{V}, E_{TN,\max}\right)$$

daily actual transpiration

maximum transpiration efficiency

Modelling canopy: Leaf Area Index

effective LAI

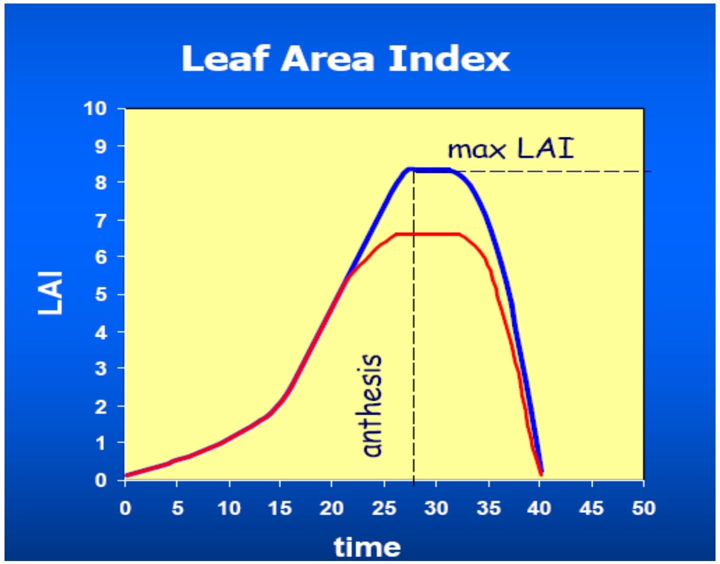
yield gap parameter

the soil water stress factor

$$\left(\frac{\partial L}{\partial t}\right) = \left(\frac{\partial L}{\partial t}\right)_{\max} C_{YG} \min\left(\frac{S}{S_{cr}}, 1\right) \qquad S = \frac{T_T}{T_{Topt}}$$

Threshold of water stress to reduce LAI

maximum LAI expansion rate



- Water stress factor reduces leaf expansion and accelerate leaf senescence.
- decrease in leaf area index affect radiation interception and transpiration, and hence crop yield

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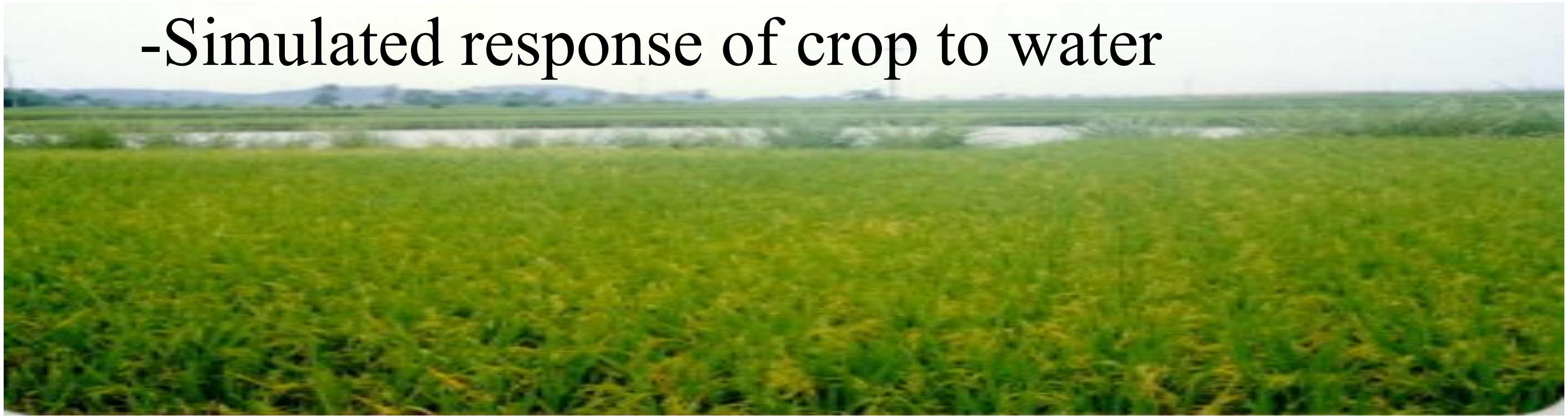
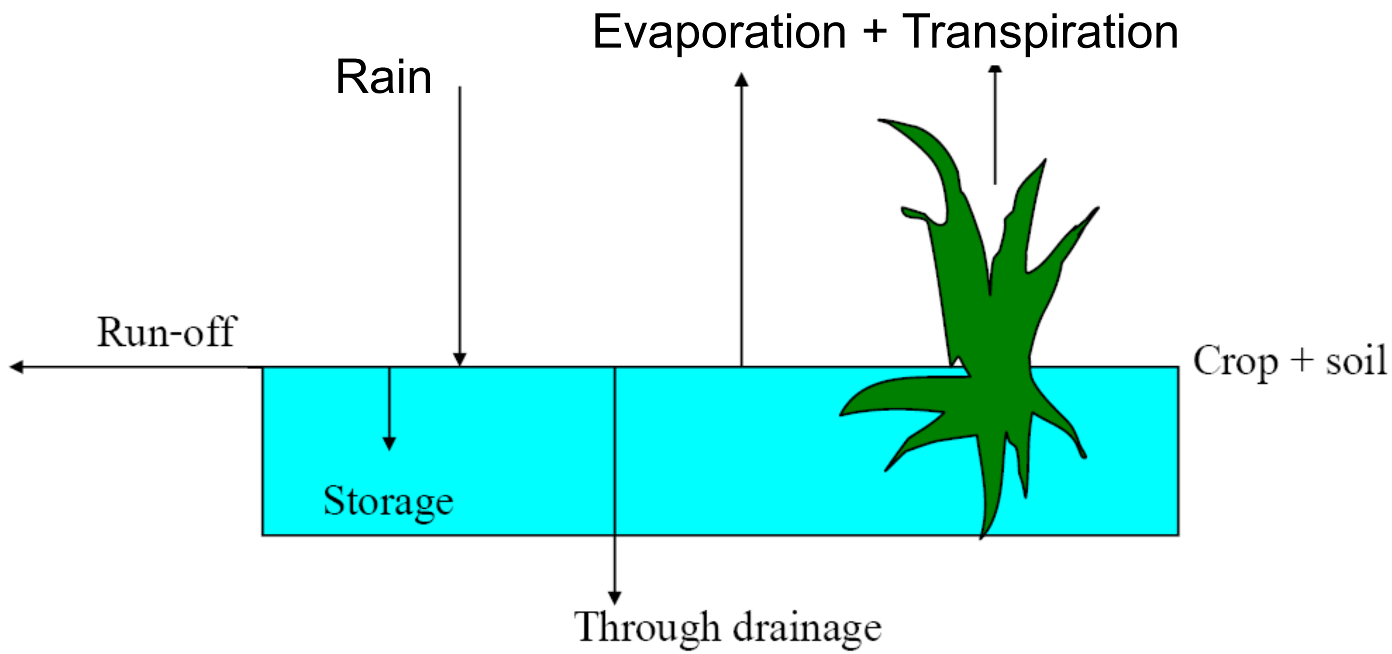
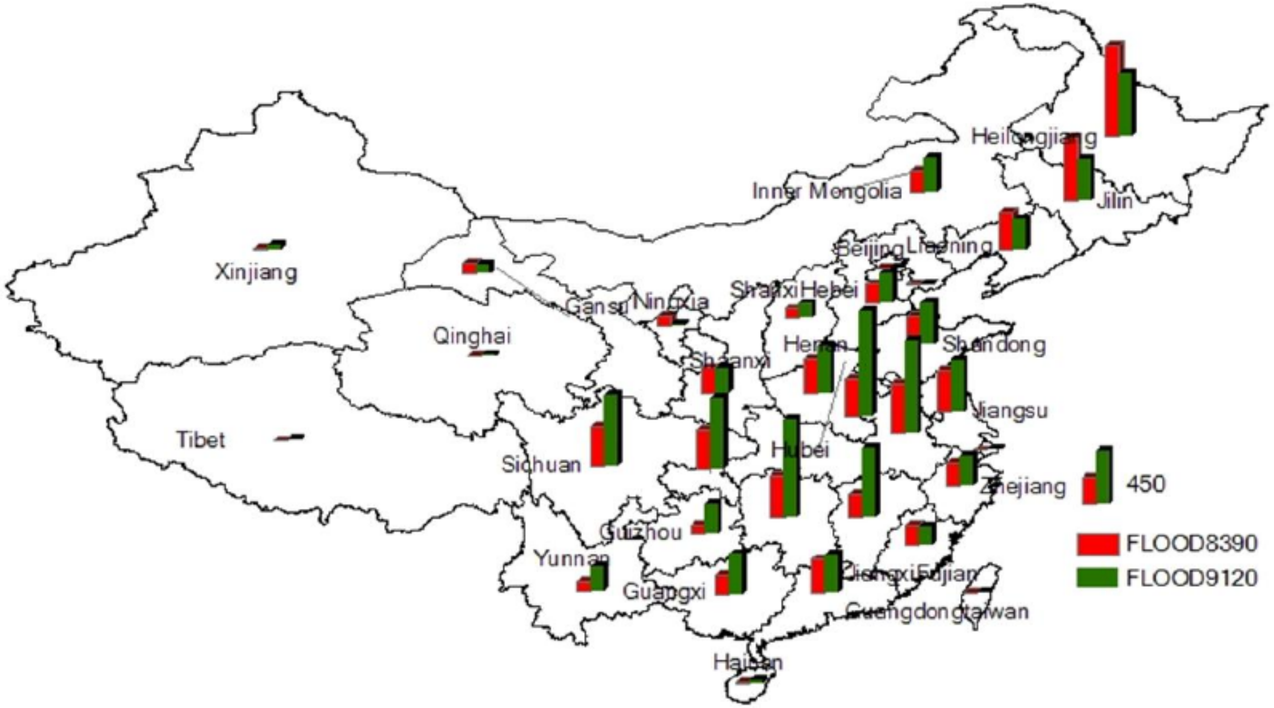


Water Balance in GLAM

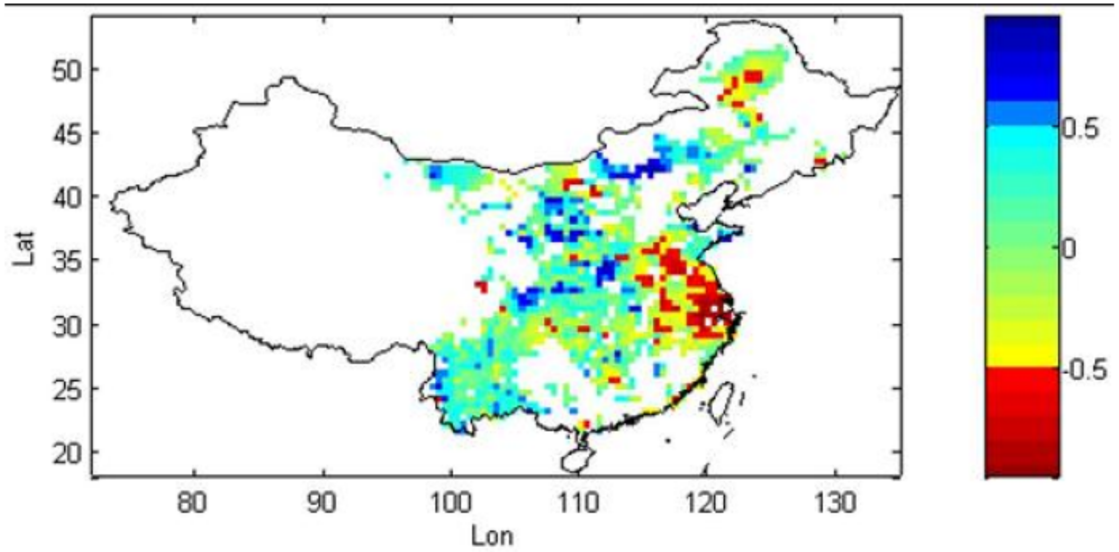


Soil water=rainfall-tranpiration-evaporation-runoff-drainage

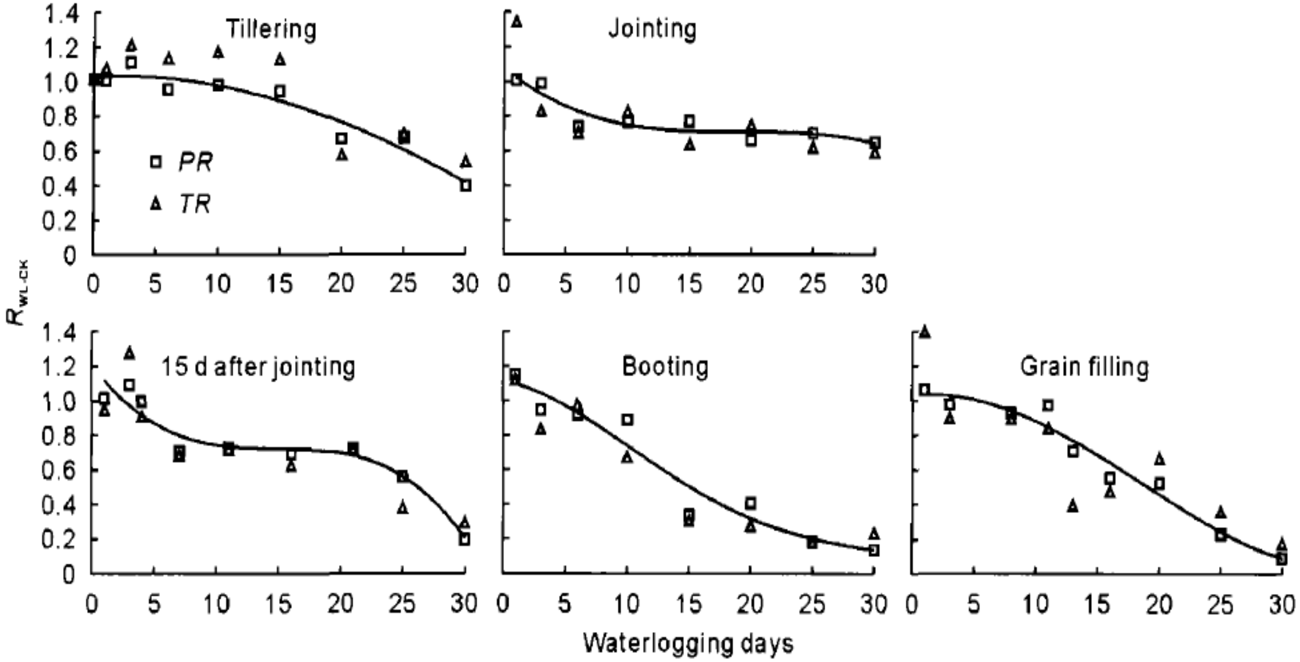
Average crop area (include maize, rice and wheat) affected by flood for 1983-1990 and 1991-2000(1000ha)



Correlation coefficient between observed wheat yield and rainfall in China



The response of transpiration to waterlogging days for winter wheat in China (Hu et al,2004)



Parameterizing the flood effect

Method 1 (Hu et al,2004)**: simulate flood effect by introducing a damage function that limited the plant's transpiration and roots growth roots when soil is greater than the field capacity**

1) Waterlogging stress factor is determined by crop species, soil water status, waterlogging days and sensitivities of different growth stages.

$$WSF = \begin{cases} 1 - WSFC_0 \times (1 - f(T_W, PDT)) \times \left(\dfrac{SW - k_{WL} \times SW_{FC}}{SW_{SAT} - k_{WL} \times SW_{FC}} \right) & k_{WL} \times SW_{FC} \leq SW < SW_{SAT} \\ 1 - WFSC_0 \times (1 - f(T_W, PDT)) & SW \geq SW_{SAT} \end{cases}$$

WSF is water stress factor

WSFC0 is the sensitivity of different crops to waterlogging

f(TW; PDT) is the response of transpiration to waterlogging days from empirical function of experimental data

Parameterizing the flood effect

Method 2(Rosenzweig et al, 2002)**:**
simulate flood effect by reducing the root growth when continuous number of waterlogging days is greater than 2 days
1)Keep count of how many continuous days soil water was at or above saturation;

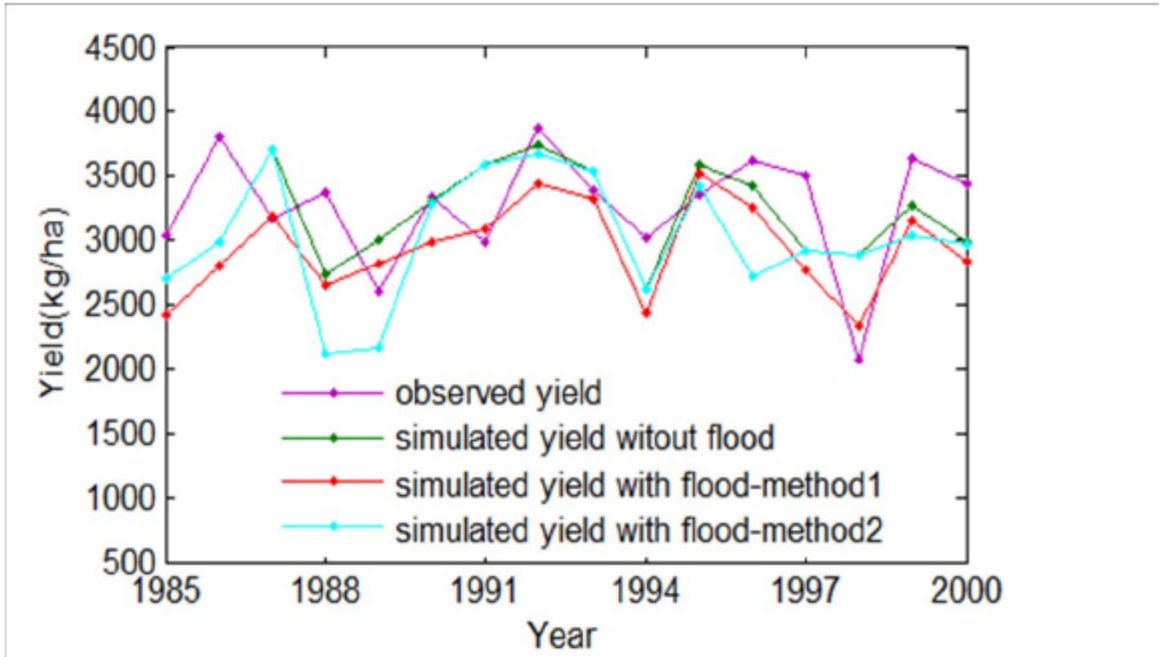
2) If the continuous number of waterlogging days was higher than 2, then set a coefficient beta to be non-zero, with a value between zero and one (default: zero);

3) Beta is parameterized in order to be able to reproduce the observed yield reductions during flooding in a specific region;

4) The amount of daily root growth is reduced by (1-beta).

Simulating the flood effect

Comparison between observed yield and simulated yield with and without flooding effect from 1985 to 2000 at 0.*5○ grid cell (31.75○N; 120.25○E)*

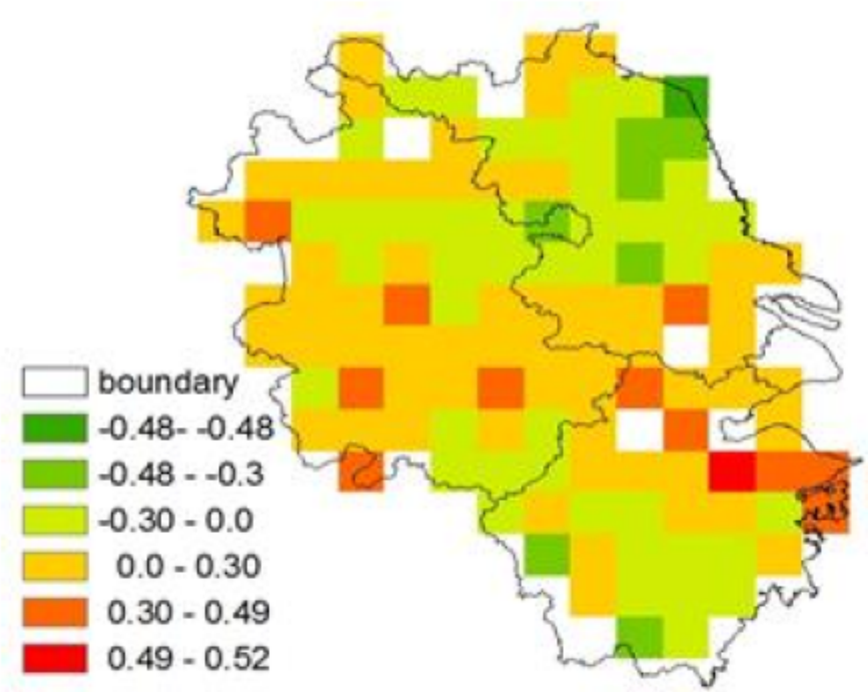


With method 1, the modified model improved yield predictions in years with serious flooding damage

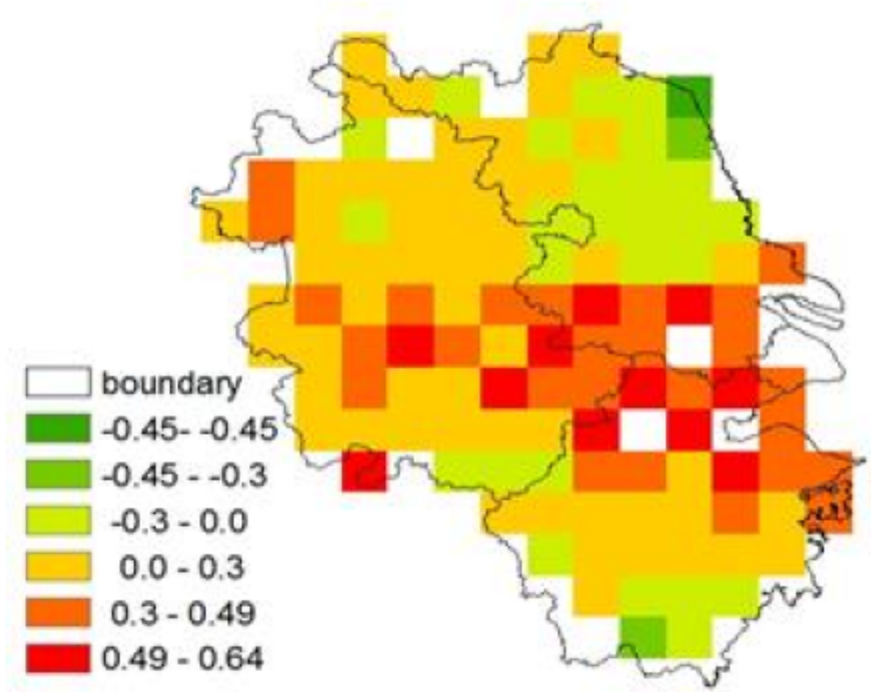
With method2 ,the flood effect on crop cannot be captured by model

Comparison of correlation coefficient between observed and simulated yield at the 0.5○ scale from 1985 to 2000

With flooding effect, yield predictions showed a better agreement with observed yield compared with no flooding effect

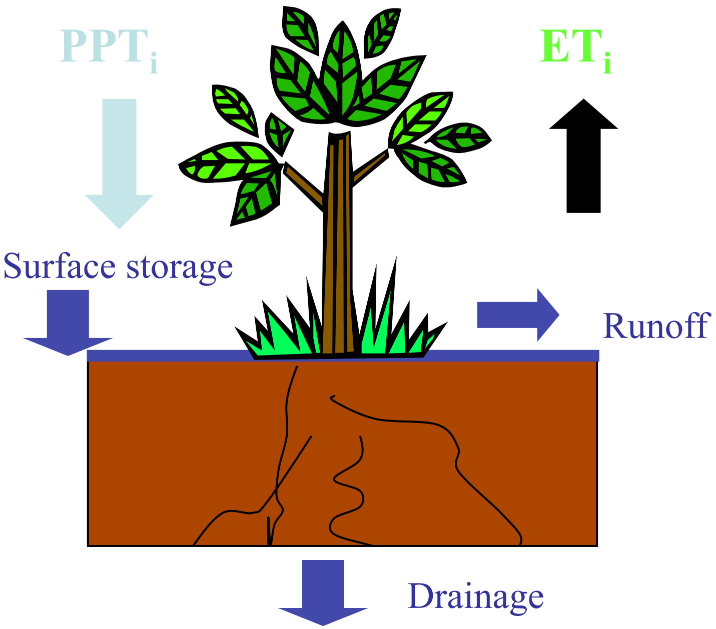


original



modified models

Crop Water Balance-surface water storage



$$SS_t = SS_{t-1} + (P + I_e - E_w - IN)\Delta t$$

SS_t Surface storage

P Precipitation intensity

I_e irrigation

E_w Evaporation rate from a shaded water surface

IN Infiltration rate

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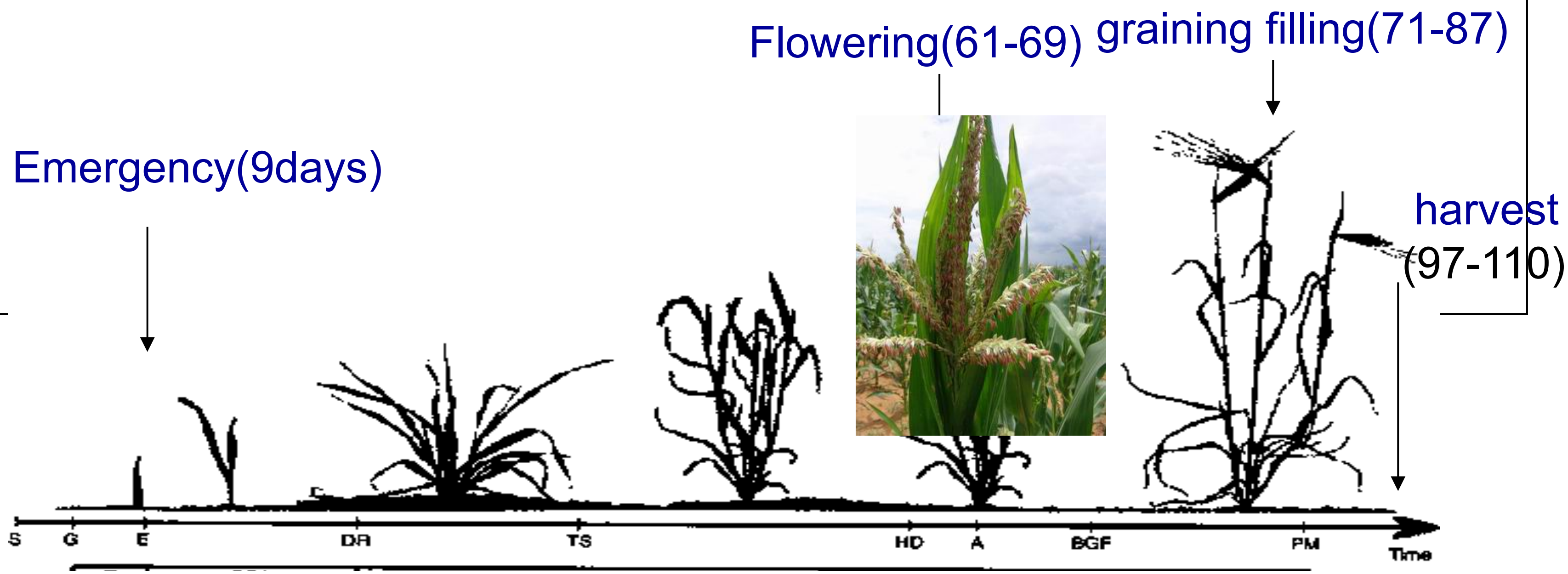
The response of crop to water at different stages

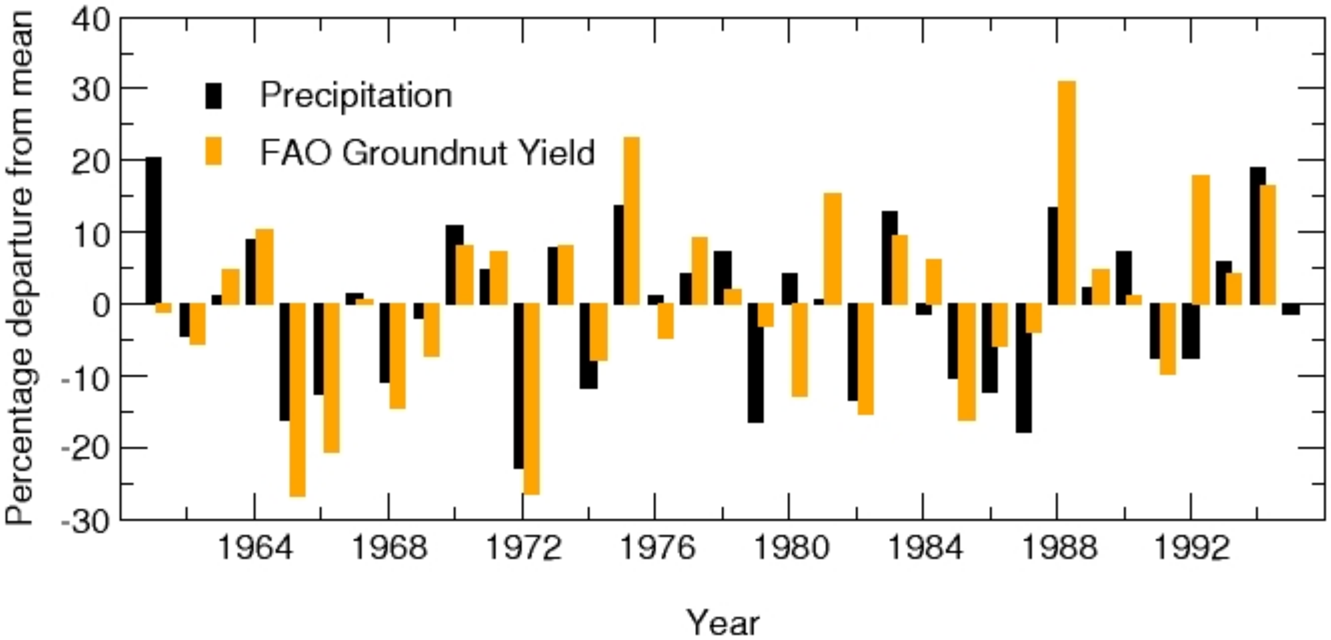
- The response of crop to weather condition defer among different stages
- The impact of water stress on grain yield is more significant during moisture-sensitive phenological stages



Water stress on crop

- Stress during early growth can stimulate root growth, extreme drought can delay planting and damage seed germination
- Stress at flowering may be more sensitive (maize)
- During the grain filling period, water deficit can reduce grain weight by accelerated senescence rate and shortened growth duration

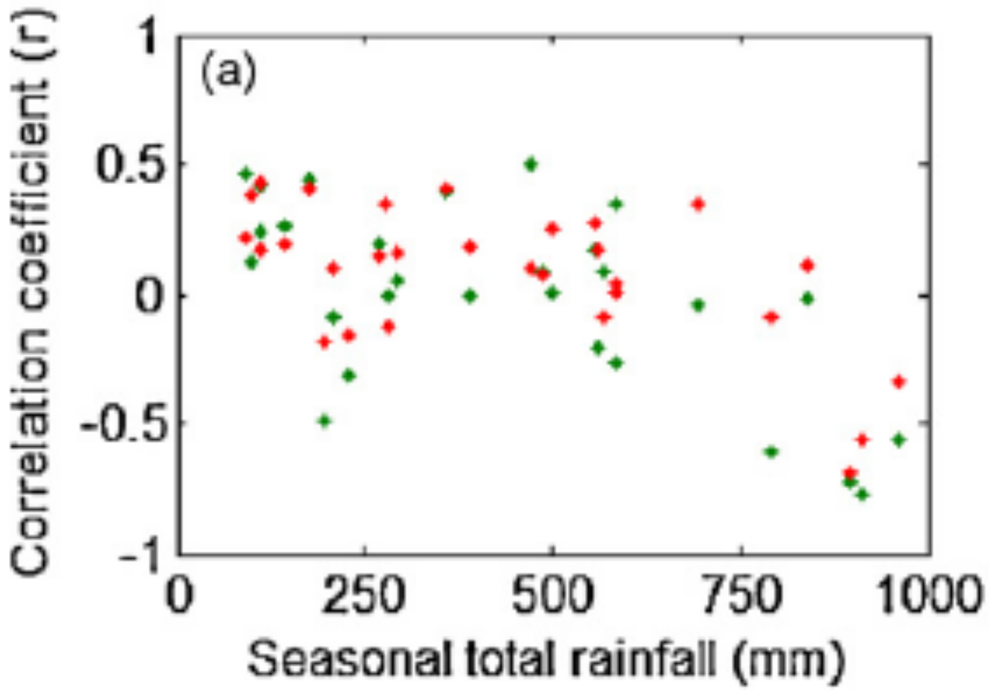
Simple correlations between rainfall and crop yield



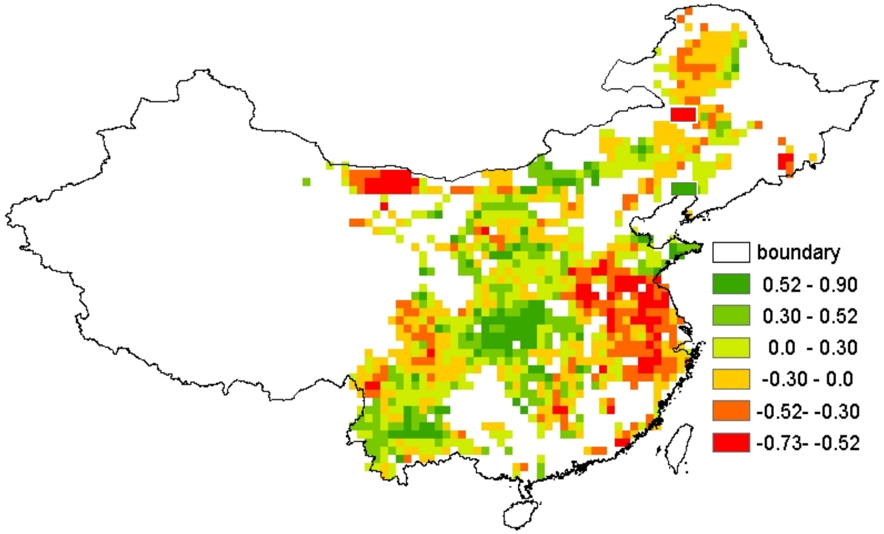
Seasonal rainfall and groundnut yields for all India.

Time trend removed. rainfall yield

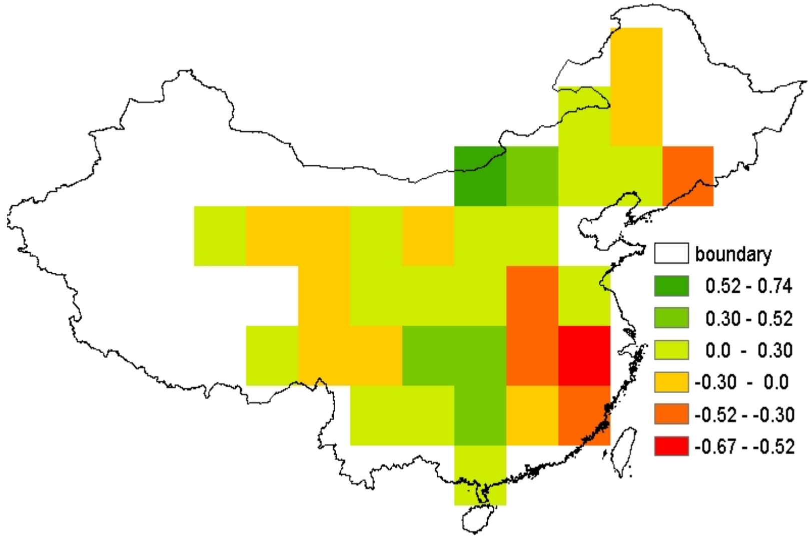
The correlation between wheat yield and seasonal rainfall at the provincial level in China for 1978–1995



Correlation between wheat yield (kg ha^{-1}) seasonal total precipitation (mm) in China for 1985-2000



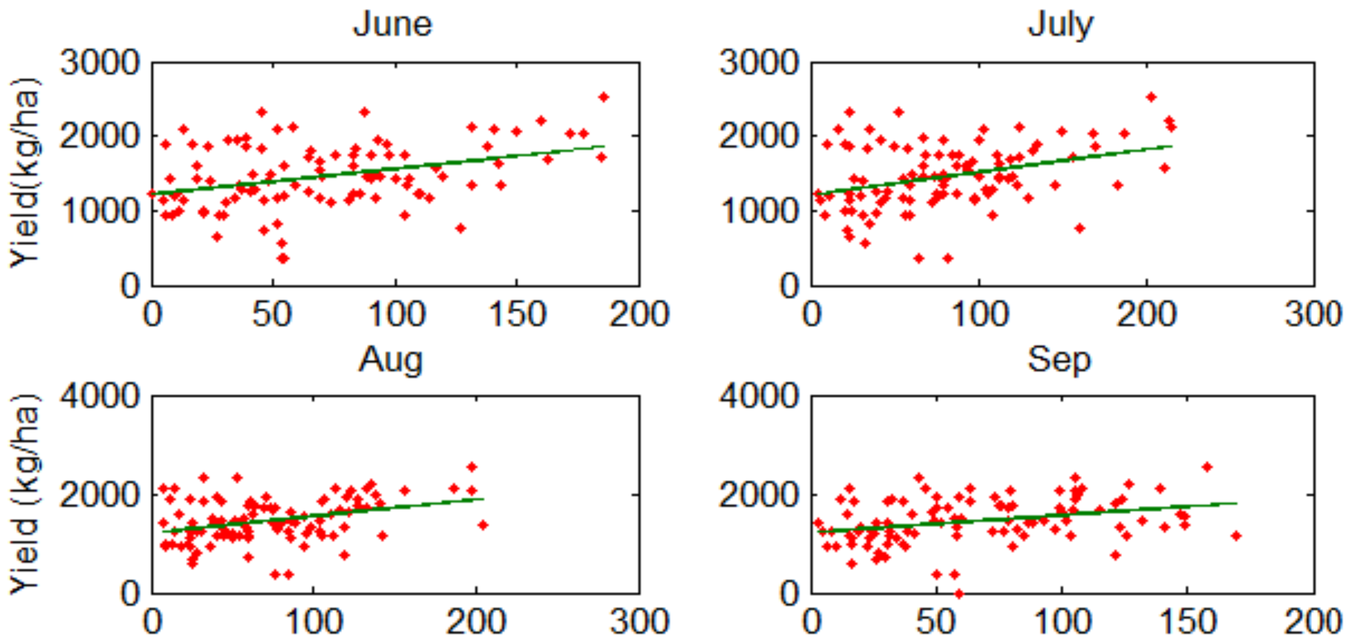
0.5º scale



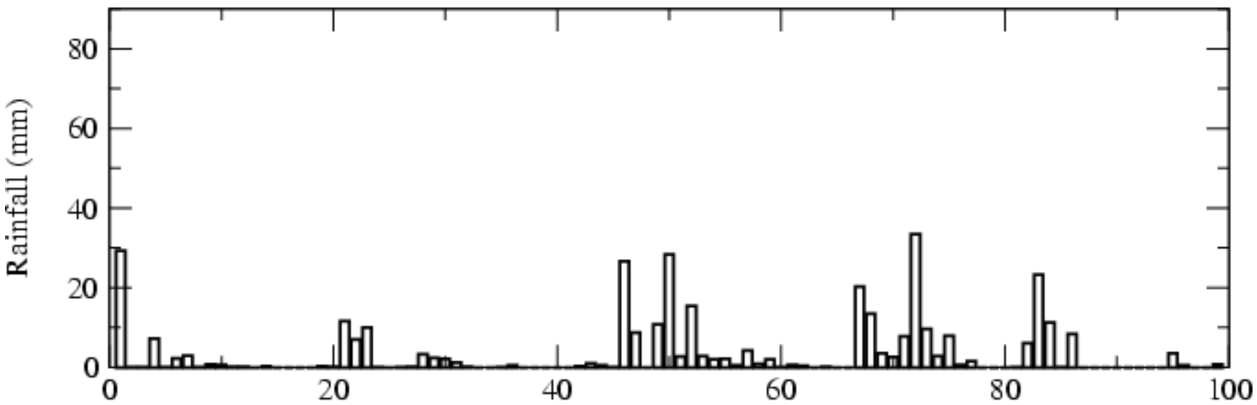
4 º scale

Grid cells with dark red and dark green show significant with $P < 0.05$

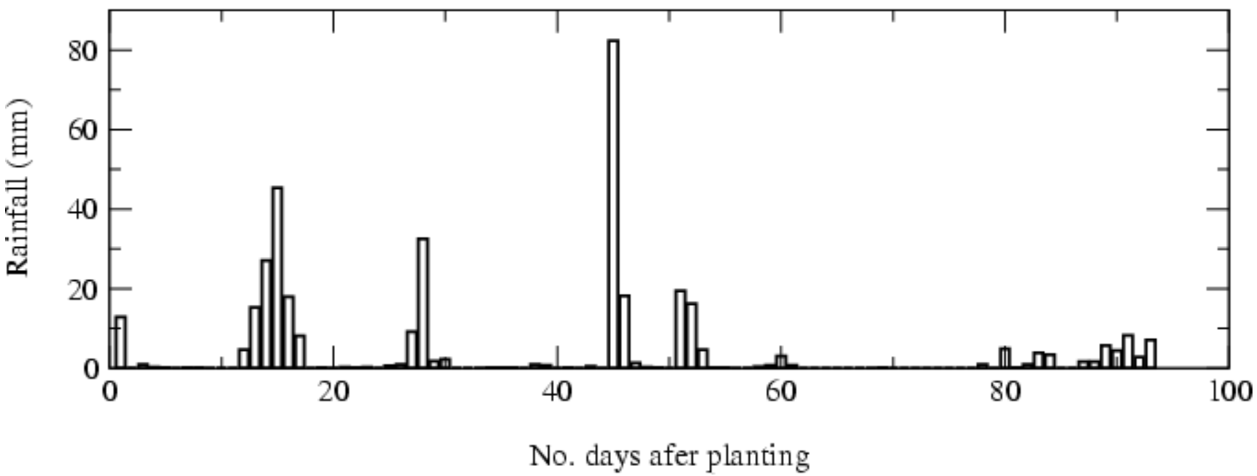
Correlation between maize yield (kg ha^{-1}) monthly total precipitation (mm) from GPCP in SNNPR Region of Ethiopia



Impact of extremes: rainfall distribution



1975
Total rainfall: 394mm
Model: 1059 kg/ha
Obs: 1360 kg/ha



1981
Total rainfall 389mm
Model: 844 kg/ha
Obs: 901 kg/ha

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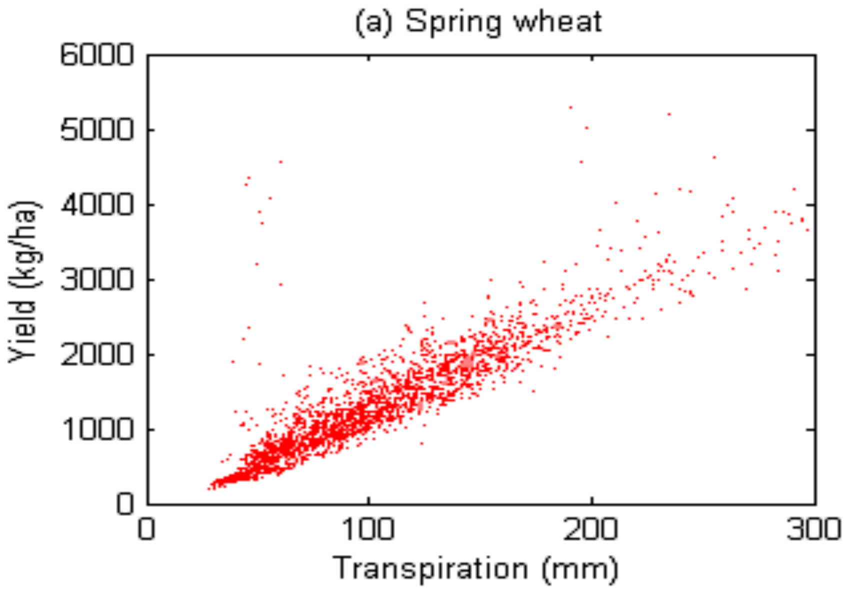
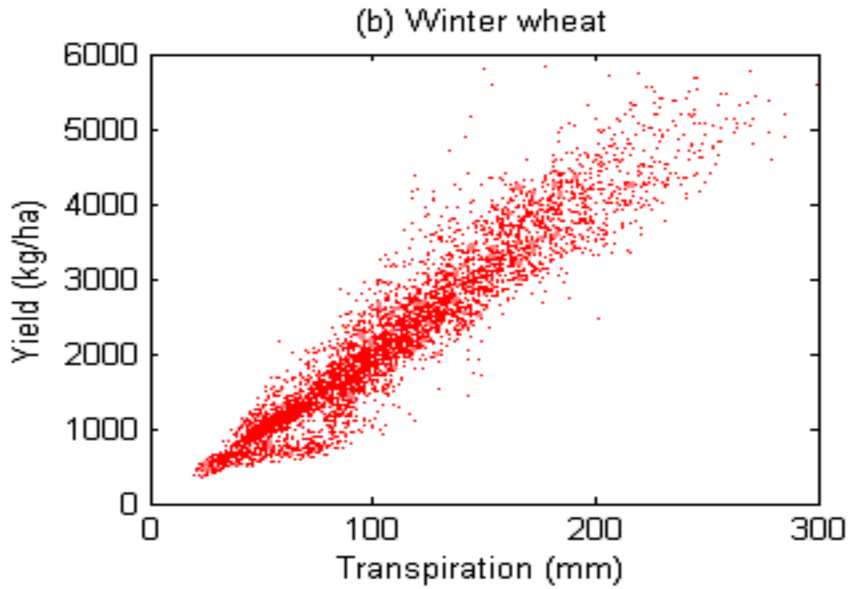
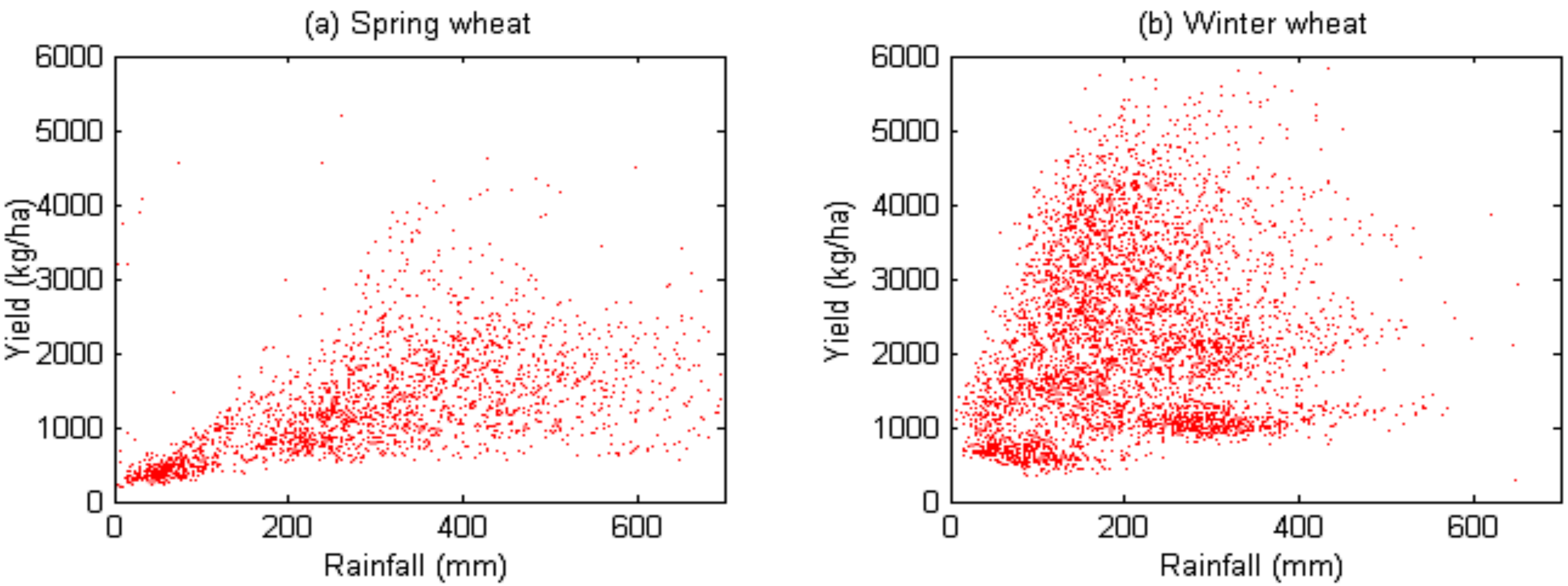
Response of simulated wheat yield from GLAM to total growing season transpiration in China

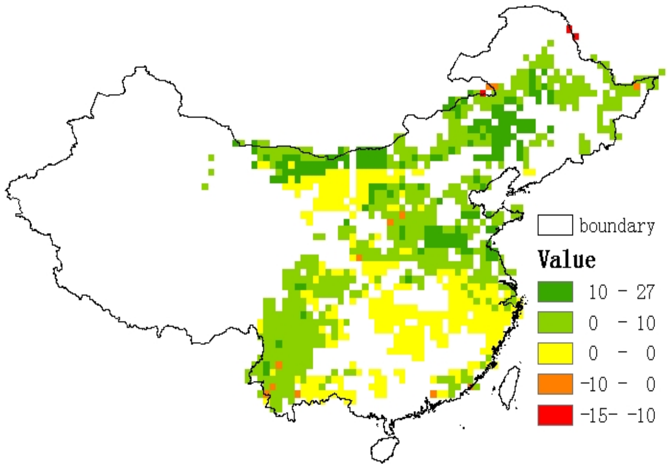




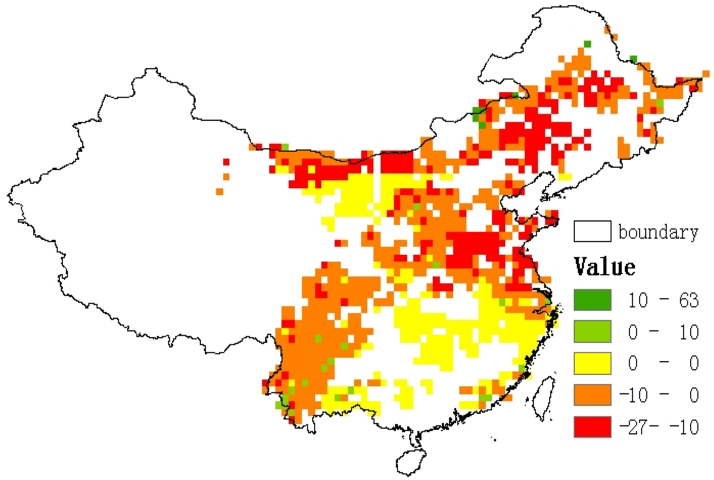
The simulated response of wheat yields to seasonal total rainfall in China



Changes in wheat yield (%) in response to a change in daily rainfall in China (%)



Changes in yield with Rainfall+25%



Changes in yield with Rainfall-25%

Crops and climate: a coupled system?

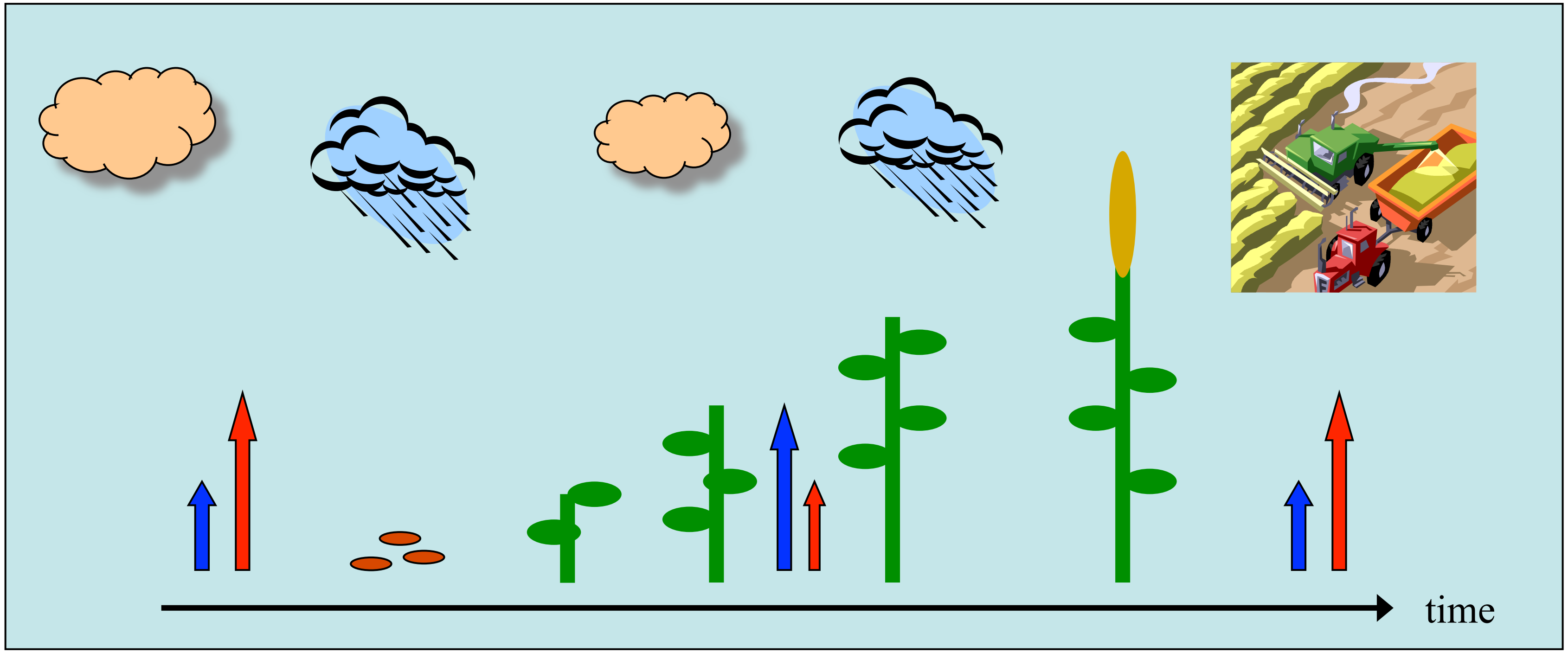
The atmosphere influences the growth of crops

temperature, humidity, rainfall, CO_2

CO_2 heat, moisture, momentum

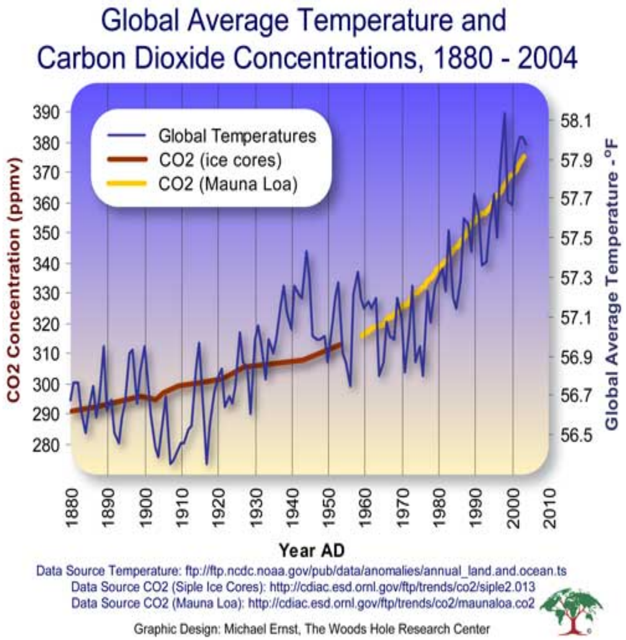
The land surface influences the state of the atmosphere

.crop grows in accordance with the simulated weather of climate model, thus altering the surface characteristics such as leaf area and canopy height, in turn influence the the surface fluxes of heat and moisture, as well as land-surface hydrological cycle.



Osborne et al (2007)

Interaction between crop water and CO_2 concentration



increase the CO2 gradient between the atmosphere and the inside of leaves,

↓

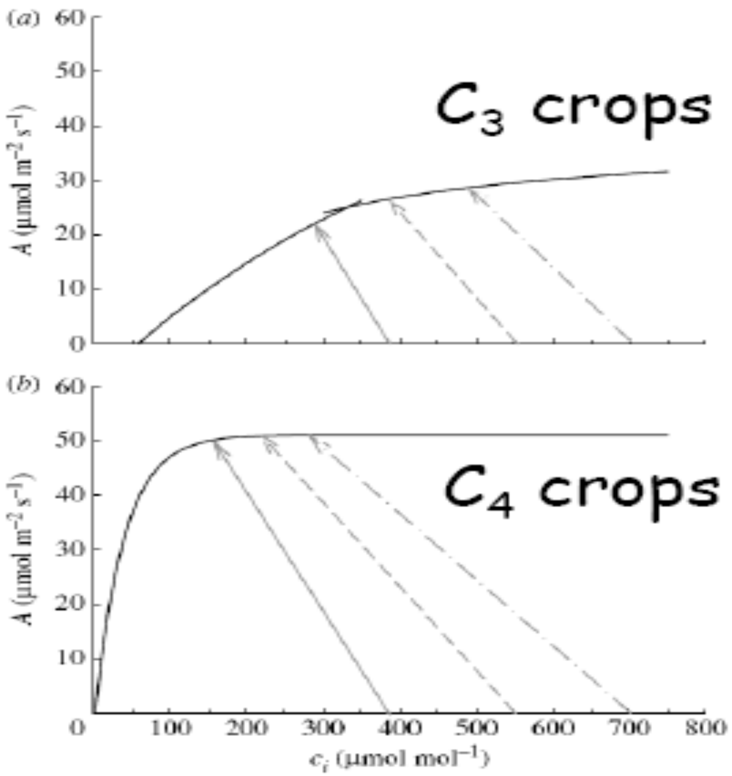
increase growth rate and productivity of plants

decrease transpiration

increase crop water use efficiency and yield

Photosynthetic response to rising CO_2

At a certain level of CO2 photosynthesis will saturate"



Soybean

Wheat

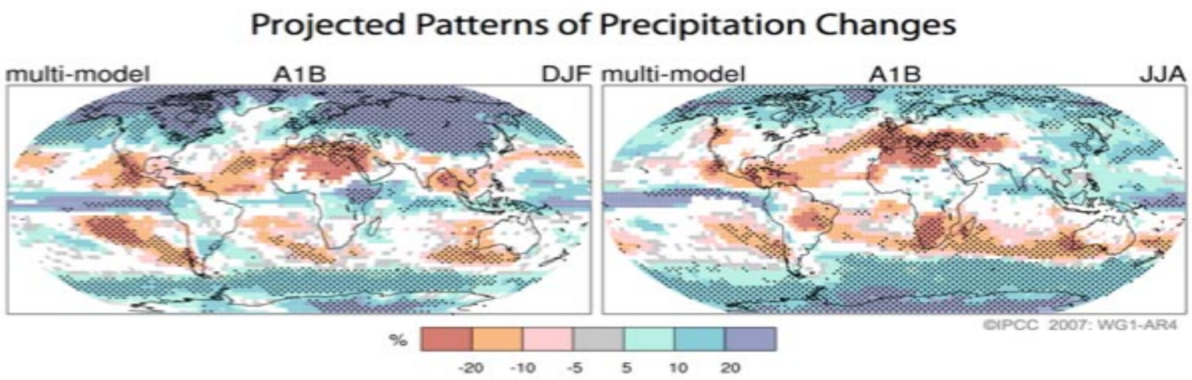
Maize Sorghum sugarcane

Precipitation in future climate

On average the world will be wetter.

➢ *Very likely* that **heavy precipitation events** will become more frequent, particularly in tropical and high-latitude areas: more flood events

➢ **Trend of drying** in mid-continental areas in summer: more drought events e.g. extreme drought increasing from 1% of present-day land area to 30% by 2100 in the A2 scenario



Effects **More humid or drier than before**

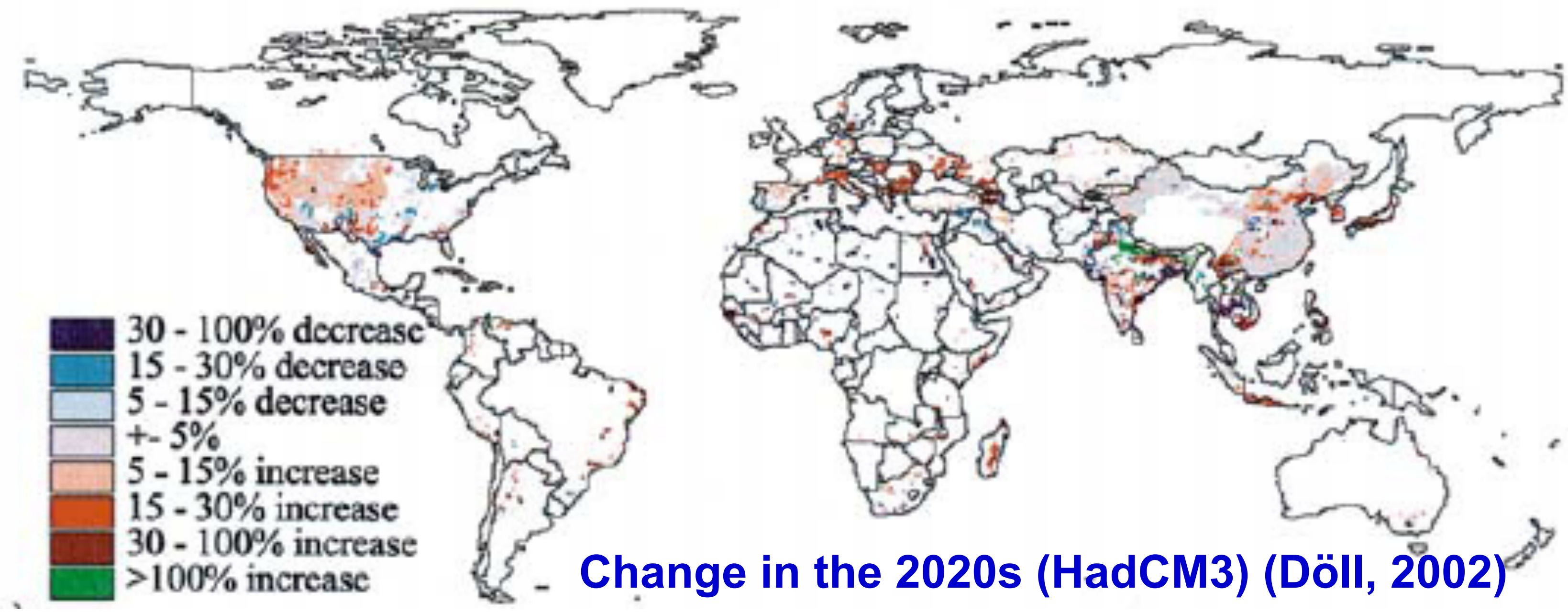
Flooding in places

Drought and rainfall variability

More severe soil erosion

pose risks to the agricultural sector and food security

Demand: Impacts of CC on irrigation water demand



Change in the 2020s (HadCM3) (Döll, 2002)

- **North of 40^{O}N**: increase
- **MENA**: decrease (shift of multicropping systems)
- **India**: general increase but decrease for border cells (changing cropping pattern)
- **China**: general negligible (<5%) but decrease in northern China
- **Global irrigation requirement** increases in 11 out of 17 world regions, but not more than 10% (except Southeast Asia with 19%)

Drought mitigation and adaptation

- Avoid stress at sensitive stages-floral initiation and pollination
- Adjusting planting structure or sowing date
- Seed Engineering-choice of cultivar tolerance to drought
- Rainfall collection based water saving
- Membrane coverage
- Protected cultivation（Less tillage and no tillage ）


Thank you
for your
attentation