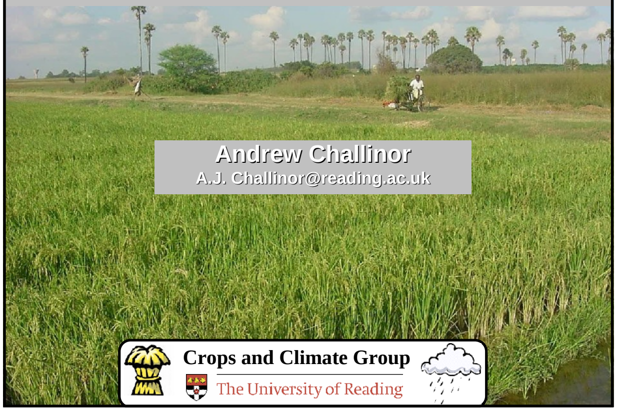
Use of RCMs for crop yield prediction



Role of RCMs in agricultural assessment

- Enabling regional-scale assessments
  - Downscaling in a physically consistent way
- Simulating physical processes more accurately
  - Hence improving accuracy of impacts assessment
- Crop forecasting methods talked about today can in principle be used with either GCM or RCM
  - In practise, higher resolution is usually better

Outline

- Crop modelling methods
- Combining crop and climate models

(See handouts — for the two items above)

- Seasonal forecasting
- Climate change
- Earth system modelling
- Use of crop yield forecasts

Crop modelling methods

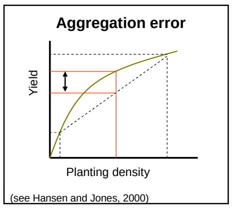
- Empirical and semi-empirical methods
  - + Low input data requirement
  - + Can be valid over large areas
  - – May not be valid as climate, crop or management change

- Process-based
  - + Simulates nonlinearities and interactions
  - – Extensive calibration is often needed
  - – skill is highest at plot-level

$\Rightarrow$What is the appropriate level of complexity?
  - – Near to the yield-determining process on the spatial scale of interest (Sinclair and Seligman, 2000)

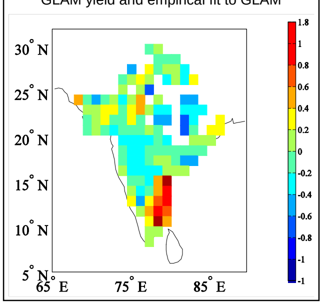
Scale issues in crop modelling

- Farm-level or large-area?
  - – Point-based estimates may be site-specific whilst grid-based analysis may omit some spatial variability
  - – Model complexity: ‘too many’ non-constrained input parameters lead to a large input data requirement, over-tuning, and uncertainty

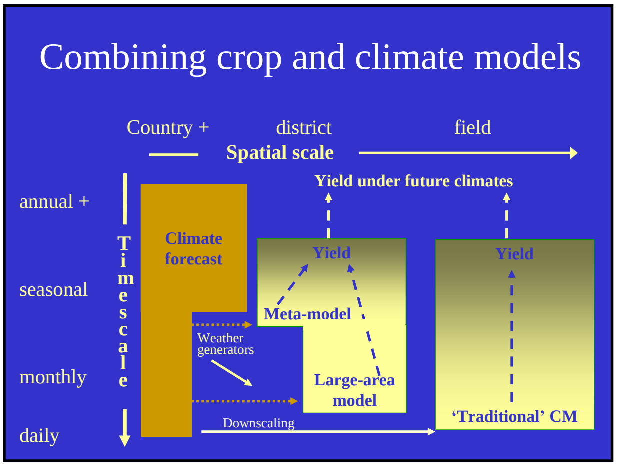


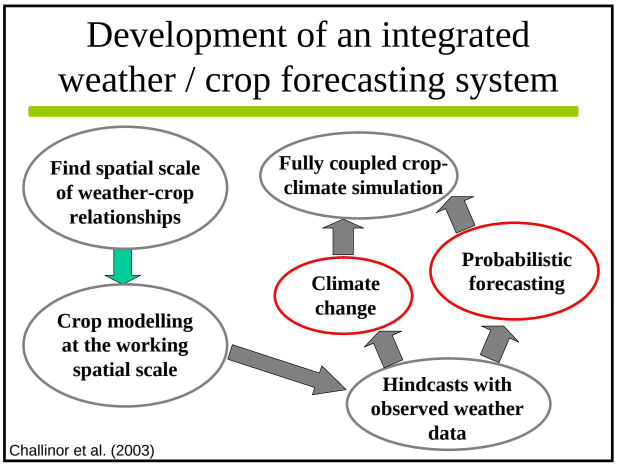
Importance of the type of crop model used

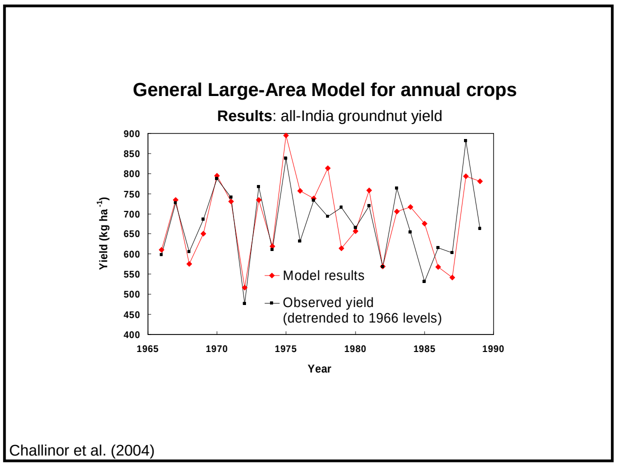
- Empirical fit to crop model often used
- Regress seasonal mean weather onto crop yield in this case
- Results in a 20 - 40% difference in simulated yields in Gujarat



Challinor et al. (2006a)


Combining crop and climate models
Country +
district
field
Spatial scale
Yield under future climates
annual +
seasonal
monthly
daily
Timescale
Climate forecast
Yield
Meta-model
Weather generators
Large-area model
Yield
'Traditional' CM
Downscaling

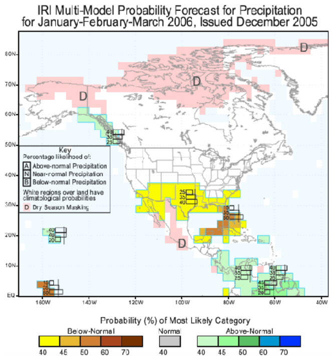

Development of an integrated weather / crop forecasting system
Find spatial scale of weather-crop relationships
Fully coupled crop-climate simulation
Climate change
Probabilistic forecasting
Crop modelling at the working spatial scale
Hindcasts with observed weather data
Challinor et al. (2003)


General Large-Area Model for annual crops
Results: all-India groundnut yield
Yield (kg ha-1)
900
850
800
750
700
650
600
550
500
450
400
1965
1970
1975
1980
1985
1990
Year
Model results
Observed yield (detrended to 1966 levels)
Challinor et al. (2004)

Seasonal Climate Prediction

Operational forecasts:

- GCMs
  - coupled ocean
  - prescribed SSTs
- Seasonal (3 mth.)
- Aggregate scale
- Probabilistic
  - Tercile shifts

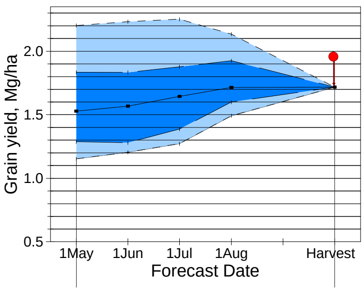


Courtesy of James Hansen, IRI

Uncertainty in Yield Prediction

1989 climatology-based Queensland Australia wheat yield forecast (Hansen et al. 2004).

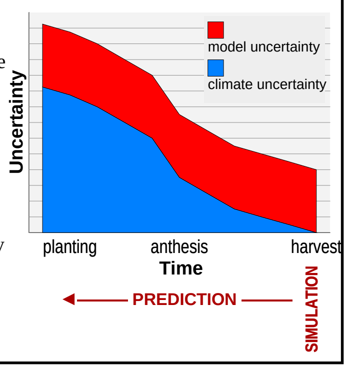
Observed (•), and 10th, 25th, 50th, 75th & 90th percentiles.



Courtesy of James Hansen, IRI

Uncertainty in Yield Prediction

- *Climate uncertainty* diminishes as forecast date advances through the season.
- *Model error* the non-climatic component.
- Relative contribution of climate, model uncertainty changes through the season.



Courtesy of James Hansen, IRI

Using the DEMETER hindcasts with GLAM: methods

- Multi-model ensemble: 7 (models) * 9 ensemble members
- Run each seasonal hindcast realisation through GLAM to create an ensemble of crop yields
- Try various bias-correction and calibration options

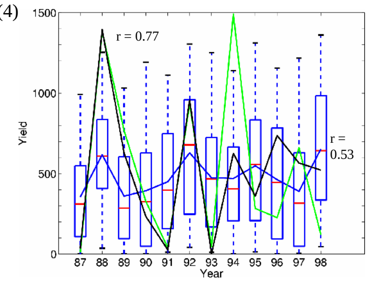
Challinor et al. (2005a)

Using the DEMETER hindcasts with GLAM: results

Control run (GCAL-BIC) output for western-most grid cell (4)

Black = Obs.
Green = ERA40

Blue = IQR, Mean
Red = Median



- This grid box has large spread (others have less)
- Low model SD exacerbated by averaging

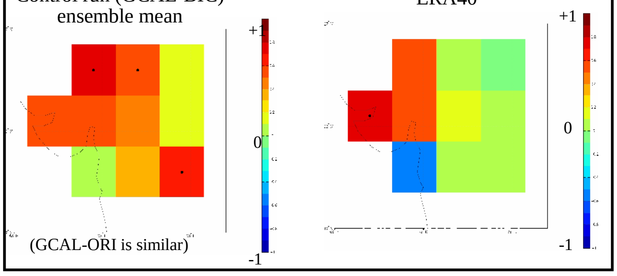
Challinor et al. (2005a)

Use of yield-ensemble means

Correlation coefficients between observed and simulated yield

Control run (GCAL-BIC) ensemble mean

ERA40



Probabilistic forecasting of crop failure

- The number of ensemble members predicting yield below a given threshold is an indication of probability of occurrence
- Found predictability in crop failure
- Less predictability in climatological yield terciles

Challinor et al. (2005a)

Aspects of climate change that are important for crops

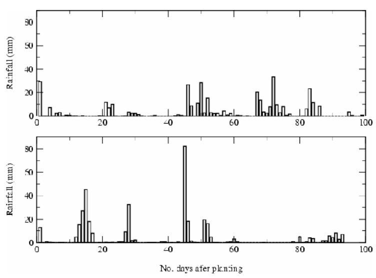
For 2100 :

- Carbon dioxide, CO_2 (emissions of 550 to 950 ppm)
- Temperature (+1.4 to +5.5 ºC)
- Rainfall amount (huge regional range)
- Variability in weather (more intense storms, increased drought risk; more frequent hot days)

from IPCC TAR (2001)

1. Changes in rainfall

Intra-seasonal variability

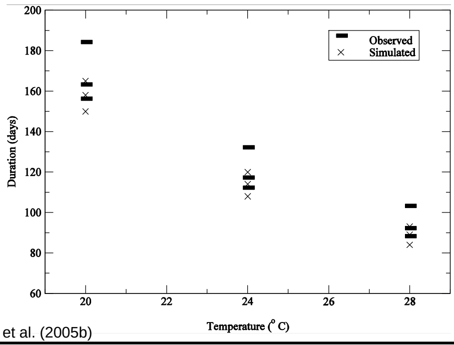


1975
Total rainfall: 394mm
Model: 1059 kg/ha
Obs: 1360 kg/ha

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

Challinor et al. (2004)

2. Higher mean temperatures => changes in crop durations



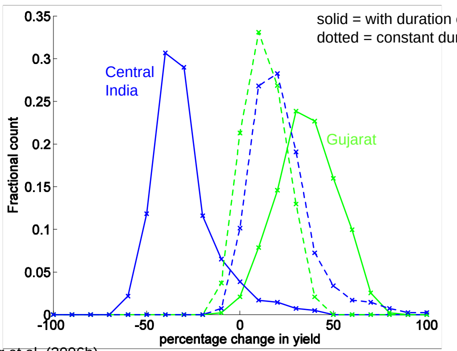
Challinor et al. (2005b)

3. CO_2 fertilisation

Free Air CO_2 Enrichment, FACE See Ainsworth and Long (2005)

Photo courtesy of Steve Long, University of Illinois

CO2 and duration changes

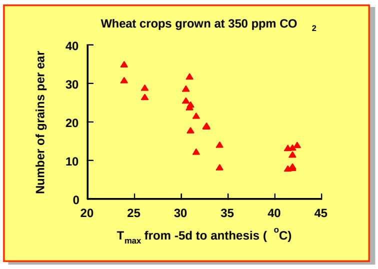


Challinor et al. (2006b)

4. High temperature threshold exceedance

Courtesy of Tim Wheeler, PEL, University of Reading

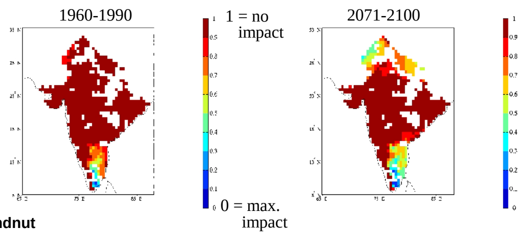
4. High temperature threshold exceedance



Wheeler et al. (2000)

The impact of water and temperature stress at flowering in one scenario

Hadley Centre PRECIS model, A2 (high emission) scenario



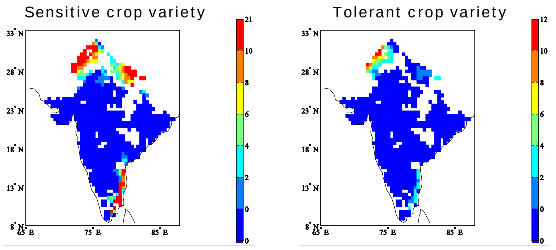
Groundnut

- Current risk is dominated by water stress; in the future climate run temperature stress dominates in the north.

Challinor et al. (2006a)

Adaptation to heat stress by changing crop variety

Number of years from period 2071-2100 when the total number of pods setting is below 50%.



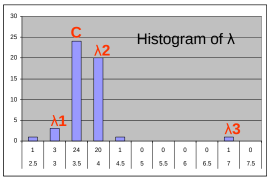
Climate: Hadley Centre PRECIS model, A2 (high emission) scenario
Crop: impact of heat stress alone using GLAM crop model Challinor et al. (2006a)

Some yield estimates to date

2 x CO_2 N. America	Wheat	-100 to +234%	Reilly and Schimmelpfennig, 1999
2 x CO_2 Africa	Maize Millet	-98 to +16% -79 to -14%	Reilly and Schimmelpfennig, 1999
2080s Africa	Cereals	-10 to +3%	Parry et al., 1999

Ensemble methods in climate change studies: (i) QUMP

- Climate model parameters varied one at a time using expert opinion to determine the values
- Present-day and 2*CO_2 runs carried out and climate sensitivity parameter (λ) measured



For GLAM-QUMP simulations:
- Choose four QUMP members with range of λ
- Large-scale cloud, sea ice or convection affected
- Define control run as λ at peak of pdf

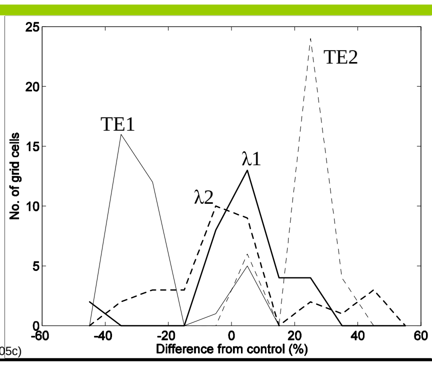
See Murphy et al. (2004)

Ensemble methods in climate change studies: (ii) GLAM simulations

- Model parameters varied one at a time
  - Rate of change of harvest index
  - Canopy extinction coefficient
  - Optimal temperature for development
  - Transpiration efficiency (TE)
- Spatial variability in optimal parameters from previous study used to determine ranges
- For 2*CO_2 use different TE range and reduce maximum transpiration rate consistently

Challinor et al. (2005c)

Uncertainty in mean yield



Challinor et al. (2005c)

Food crops in a changing climate

Tuesday 26 to Wednesday 27 April 2005
Discussion Meeting
Location: Royal Society
Address:
6–9 Carlton House Terrace
London
SW1Y 5AG

Food crop production is inherently sensitive to climate and weather. Changes in both the mean and the variability of climate, whether naturally forced (eg El Nino), or due to human activities, pose a threat to crop production globally. This meeting considers how to forecast the impacts of climate variability and change on food crops, including the climatic aspects of food security in Africa.

Food crops in a changing climate (Adobe PDF File, 26kb)

Andrew Challinor, Tim Wheeler, Julia Slingo, Brian Hoskins

Phil. Trans. Roy. Soc. B 360 (1463) 1981-2194

Special offer: £45 (usually £115)
Email Debbie.Vaughan@royalsoc.ac.uk

Crops and atmospheric composition: O_3

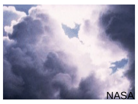
- Industrial emissions resulting in increased surface ozone are predicted to rise
  - Predictions for China particularly high
- Ozone lowers the photosynthetic rate and accelerates leaf senescence
  - ~5% yield reductions currently; 30% in 2050?
- Few experiments with either CO_2 or O_3 carried out in the tropics, where most of the world's food is grown

Crop greenhouse gas emissions

- Methane from paddy rice
- Nitrous oxide when synthetic fertilizers are used
- Agriculture may account for 50% of future emissions
- So, adaptation to climate change needs to be carefully thought out
- Also, atmospheric composition and soil fertility will interact in non-linear ways with water and heat stress
  - **Feedbacks**

An integrated approach to impact assessments

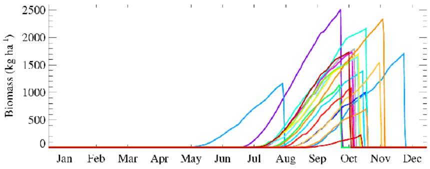
- Crops can modify their own environment
  - The water cycle and surface temperatures vary according to land use
- Integrate biological and physical modelling
  - By working on common spatial scale
  - By fully coupling the models



Fully coupled crop-climate simulation

- Resolve diurnal cycle
- Study feedbacks
- Integrate land-use patterns

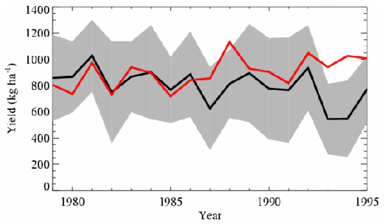
Crops 'growing' in HadAM3 (NW India)



Challinor et al. (2006a)

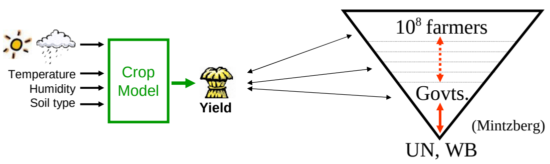
Fully coupled crop-climate simulation

All-India FAO groundnut yield (red) with simulated mean yield (black) and spatial standard deviation (grey shading).



Challinor et al. (2006a)

Use of crop yield forecasts



- Importance of quantifying uncertainty
- Information for planning and/or adaptation
- Different groups interested in different time horizons
- Projected costs of climate change may influence CO_2 emissions
- Arrows are two-way

References

Ainsworth, E. A. and S. P. Long (2005). What have we learned from 15 years of free-air CO_2 enrichment (FACE)? A meta{analytic review of the responses of photosynthesis, canopy properties and plant production to rising CO_2. New Phytologist 165, 351-372.

Challinor, A. J., T. R. Wheeler, T. M. Osborne and J. M. Slingo (2006a). Assessing the vulnerability of crop productivity to climate change thresholds

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Sinclair, T. R. and N. Seligman (2000). Criteria for publishing papers on crop modelling. Field Crops Research 68, 165-172.

Wheeler, T. R., P. Q. Craufurd, R. H. Ellis, J. R. Porter, and P. V. Vara Prasad (2000). Temperature variability and the annual yield of crops. Agric. Ecosyst. Environ. 82, 159-167.