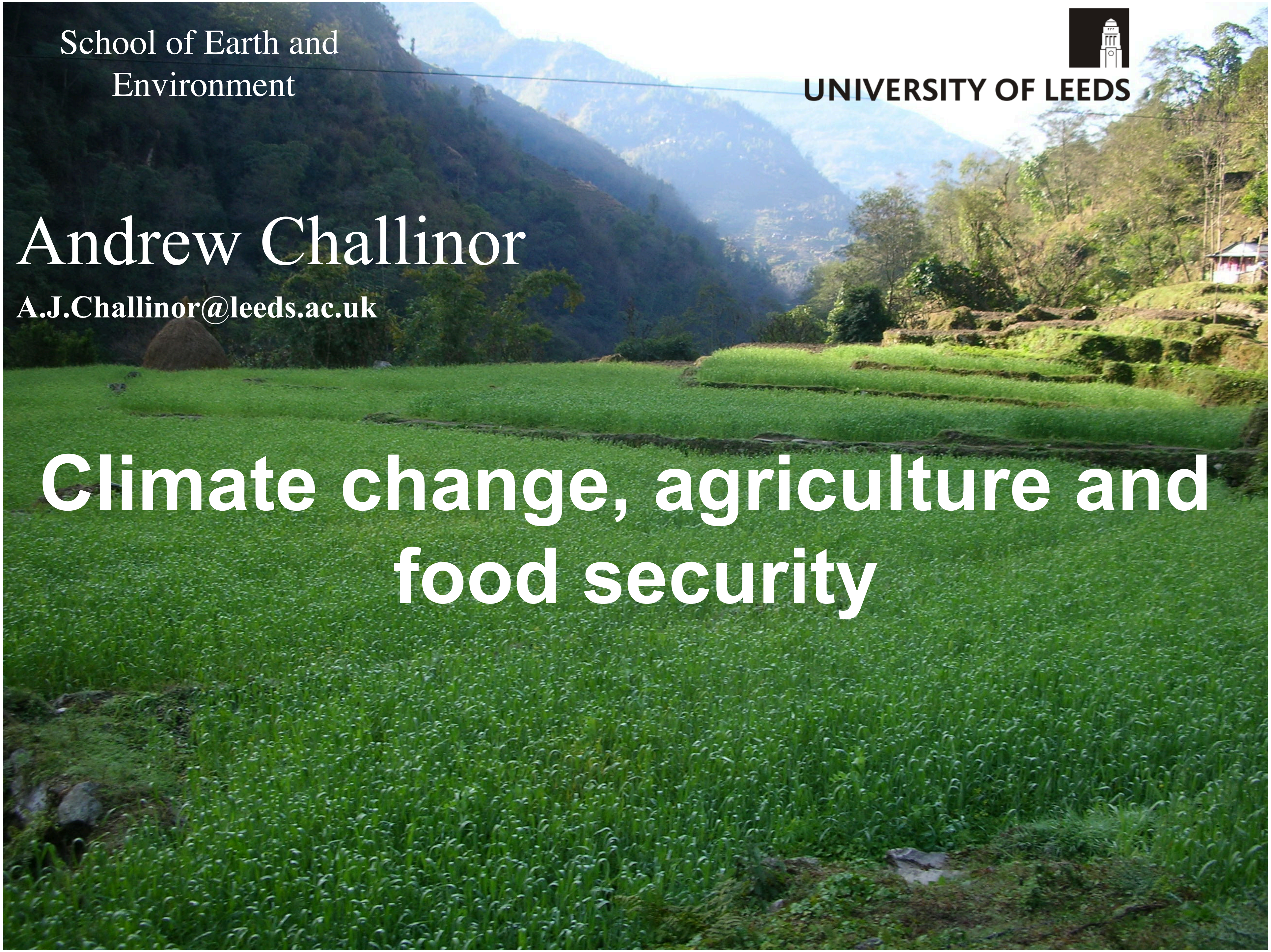


School of Earth and Environment

UNIVERSITY OF LEEDS

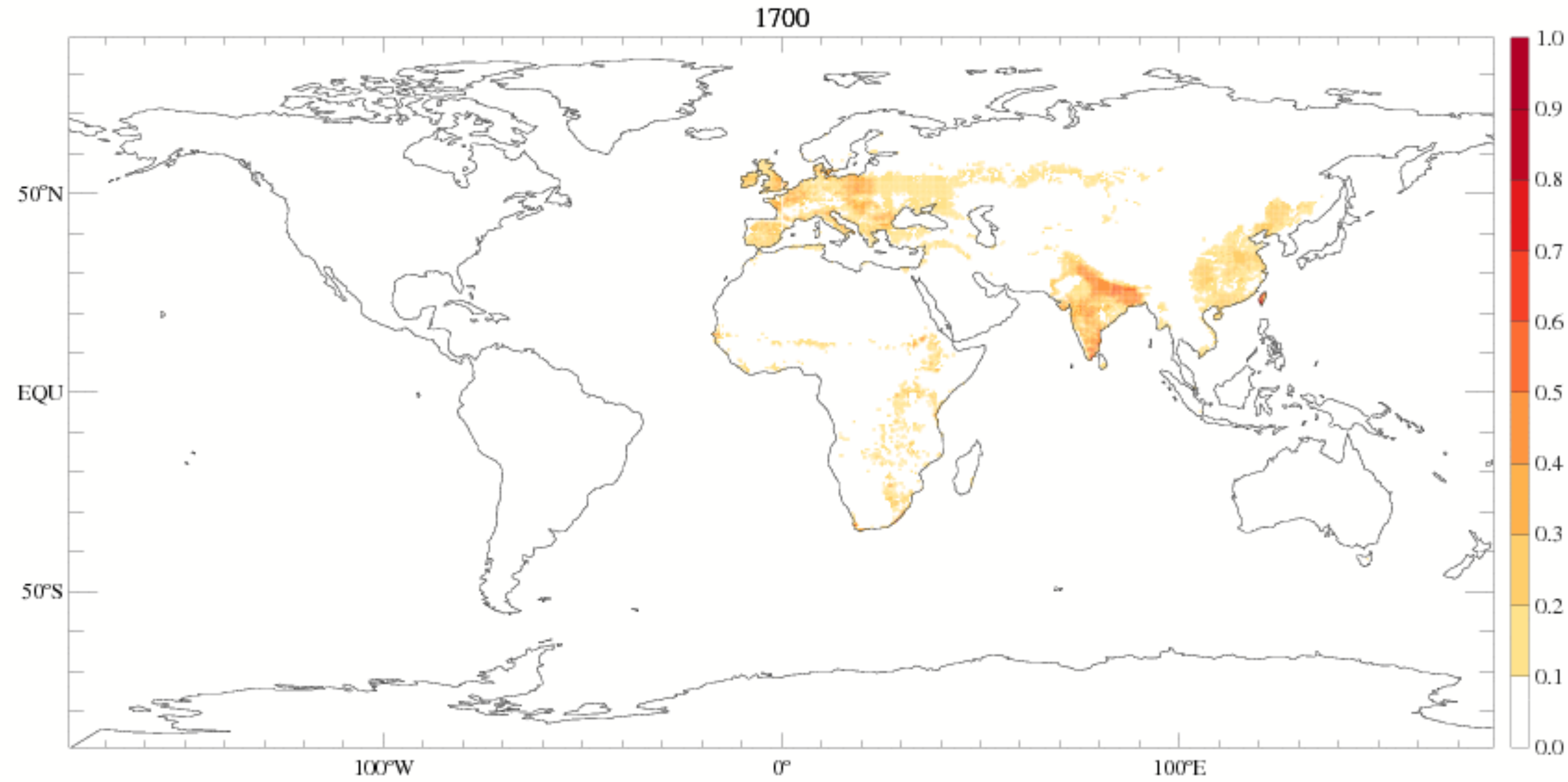
Andrew Challinor

A.J.Challinor@leeds.ac.uk

Climate change, agriculture and food security


~25 miles
http://earthobservatory.nasa.gov

The food component of the earth system

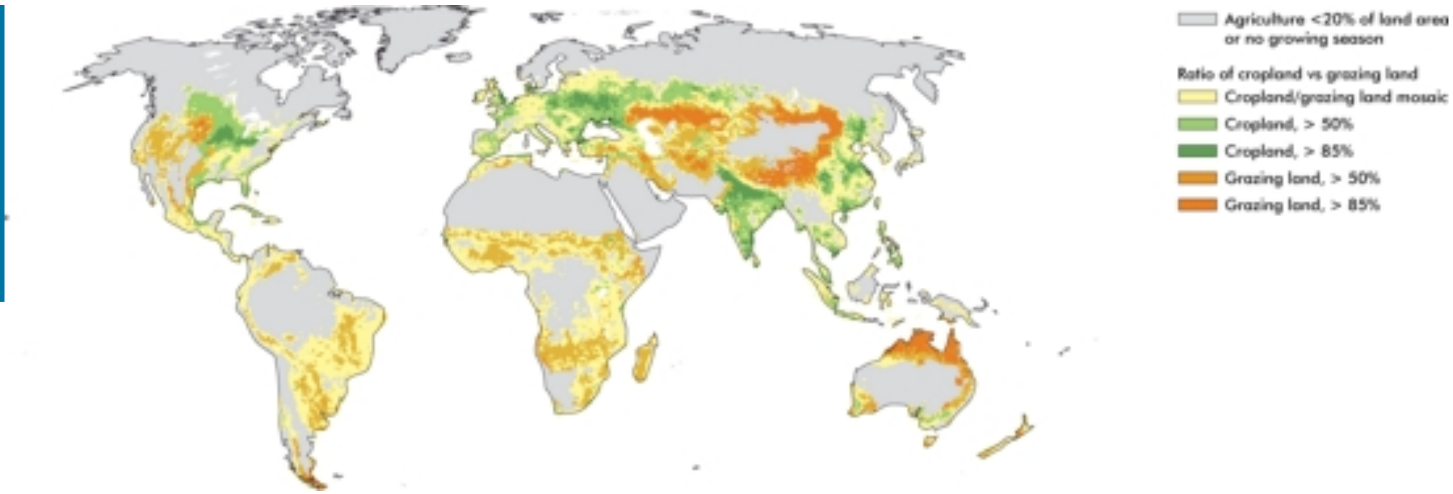


Source: www.sage.wisc.edu

Global food: the big picture

- As countries develop, diet changes from crop to meat
  - e.g. China – demand increasing 2x faster than pop growth
  - A healthy vegetarian diet requires 0.2ha, a meat-based diet requires 1.4ha because a kg of meat requires 6 kg of grain to produce
- Projections suggest global demand will be for **~2x** more food (but with big range)

Global farming



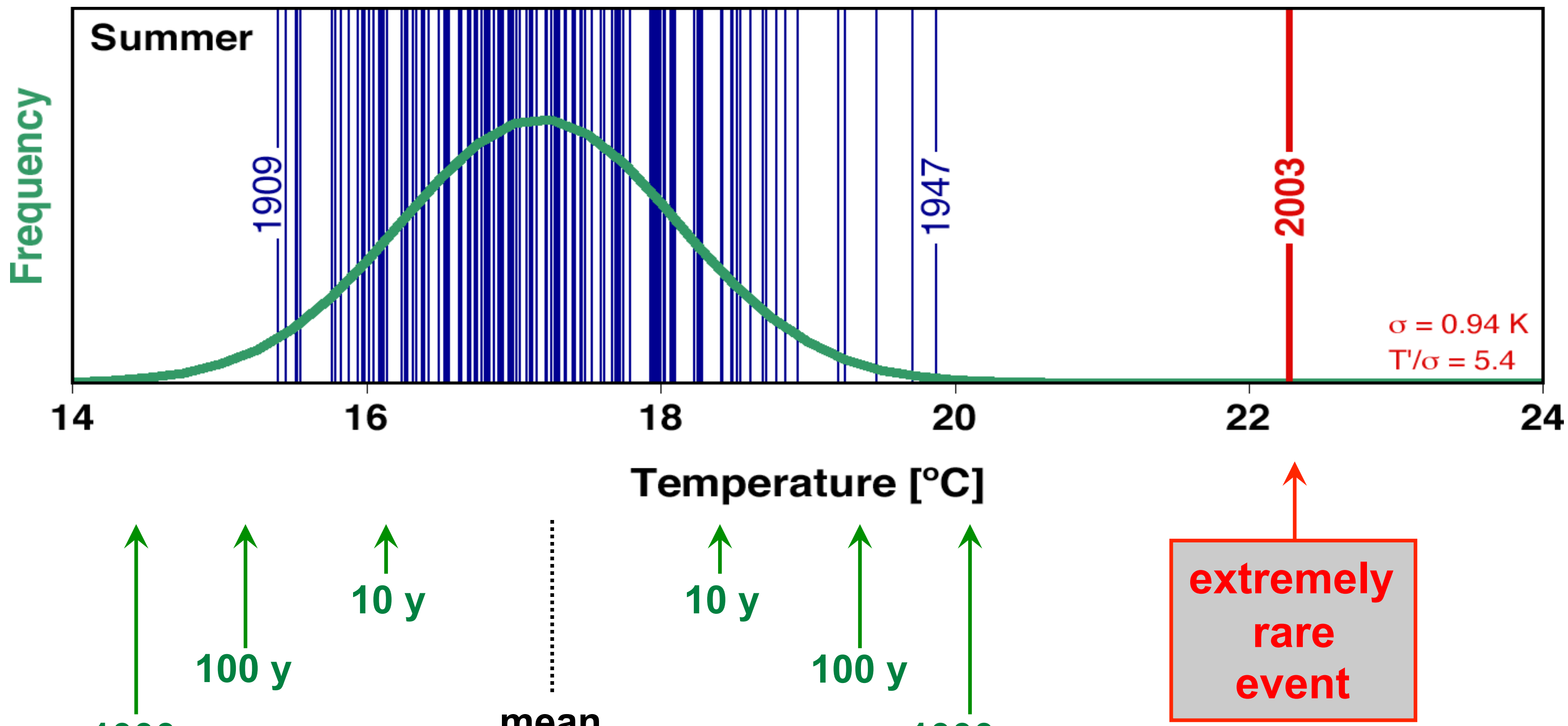
- Global land area is 13.4b ha
  - Current crop land is 1.53 b ha
  - Current pastureland is 3.44 b ha
- Land with potential for crops is estimated to be 3.32 b ha
  - i.e. potential for expansion of 2.16 x in crop area
- But this includes 0.77 b ha of forests, and land other land is not “prime”

Globally, we need about 2x the food, but:

- Biofuels will take land out of cropfood production
- Potential for yield loss as move to a “low carbon” economy
- Environmental change

European heat-wave 2003 - estimation of return periods

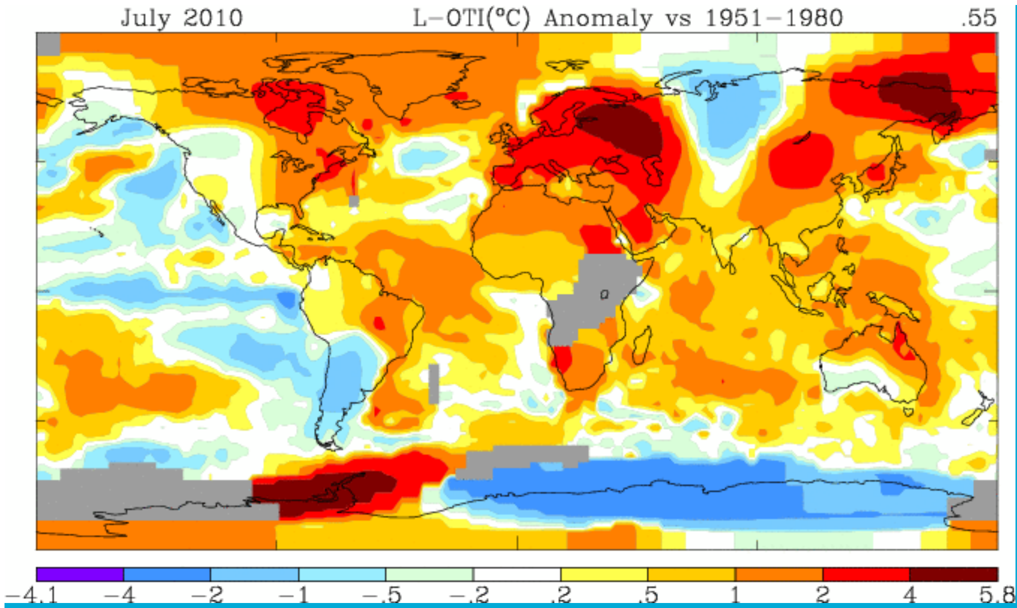
Swiss Temperature Series 1864-2003 (mean of 4 stations)



(*Schär et al. 2004, Nature, 427, 332-336)*)

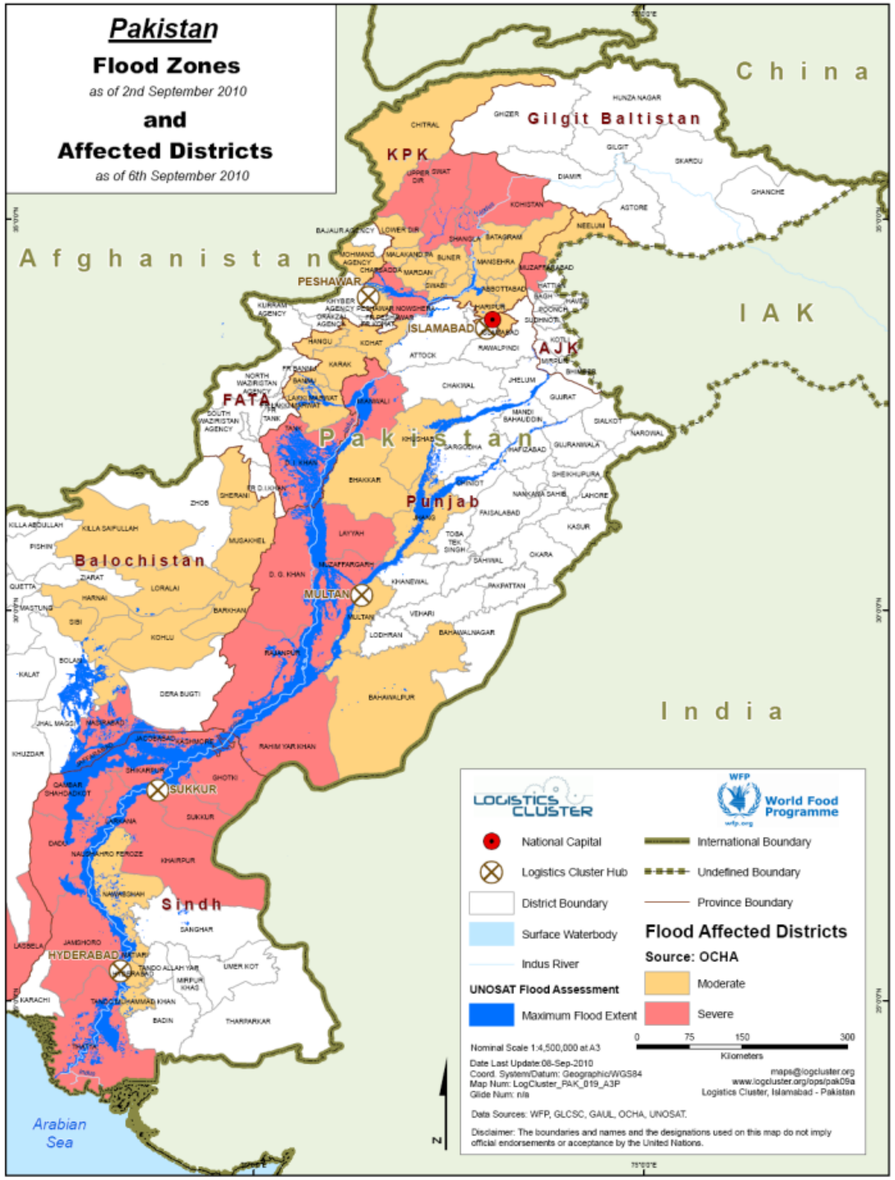
More elaborate analysis shows it likely that most of the risk of the event due to increase in greenhouse gases - also that by 2050, likely to be average event and by 2100 a cool event (*Stott et al 2004, Nature 432 610-614*).

Goddard GHCN_GISS_HR2SST_1200km _Anom07_2010_2010_1951_1980

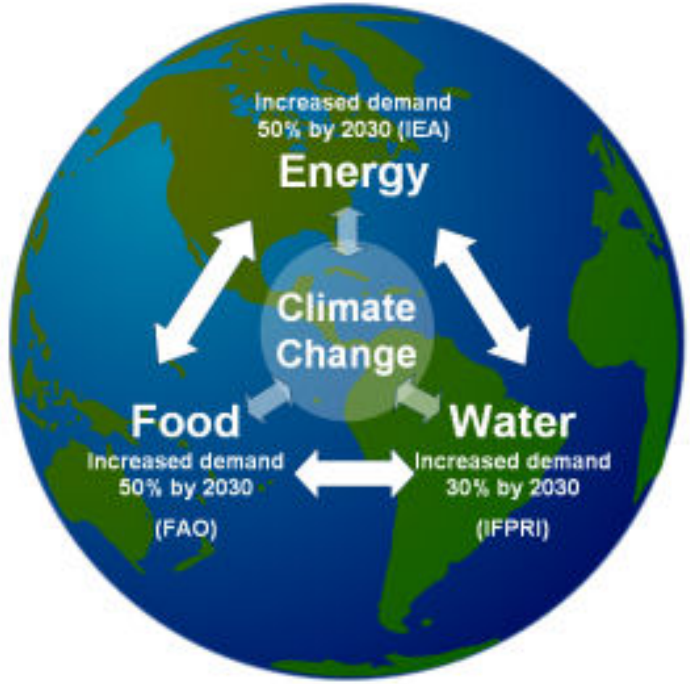


Russia and Pakistan, 2010

Logistics cluster, Islamabad



The challenge



- Increase food production
  - in the face of climate change
  - whilst reducing the carbon cost of farming
  - but not simply by farming at lower intensity and taking more land (because there isn't enough)
- Beddington's *Perfect Storm*


FAO Food Price Index
2002-2004=100
250
210
170
130
90
50
90 91 92 93 94 95 96 97 98 99 00 01 02 03 04 05 06 07 08 09 10 11
* The real price index is the nominal price index deflated by the World Bank Manufactures Unit Value Index (MUV)

Climate impacts Group

Overview

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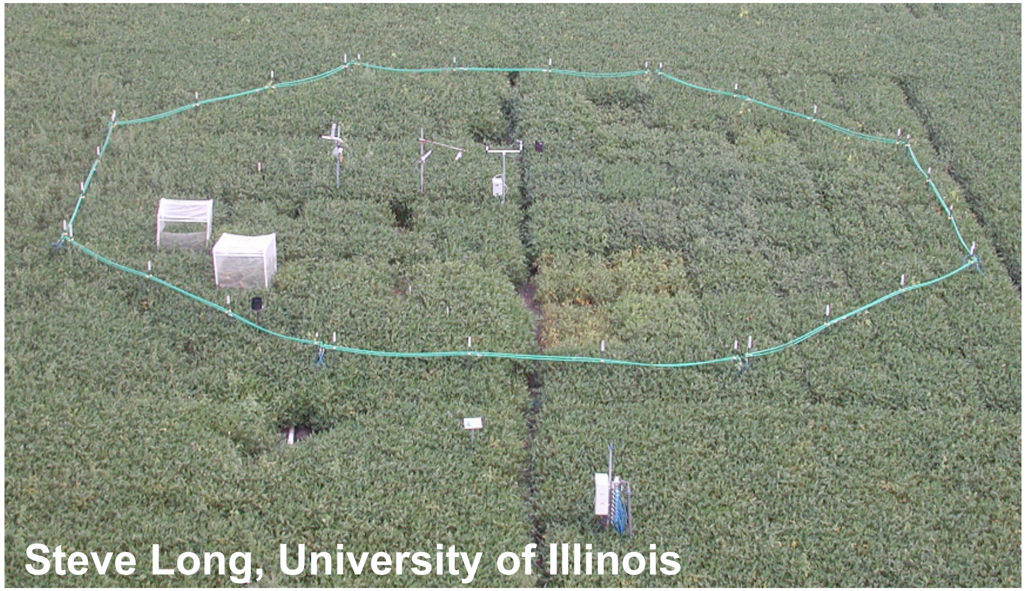
1. **Assessing future food production and food security**
   - **Methods (today)**
   - Results (tomorrow)
2. Treatment of uncertainty and managing risks
3. Climate-resilient pathways and adaptation

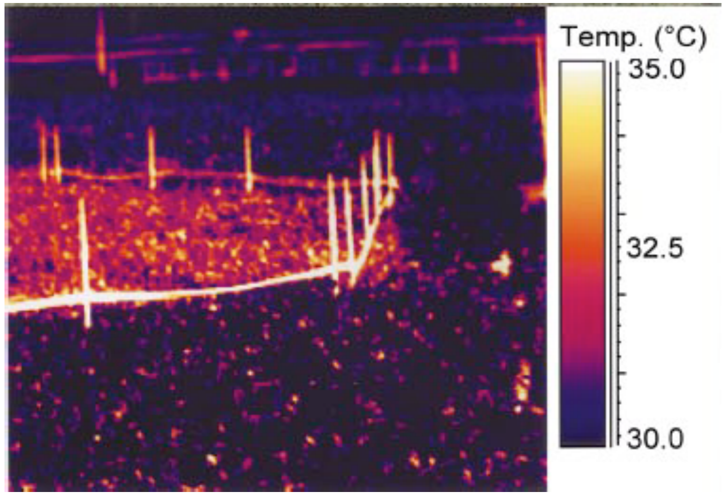
Controlled environment experiments

Plant Environment Laboratory, University of Reading

Elevated carbon dioxide

Free Air CO2 Enrichment





Long, et al., 2004

- Elevated CO_2 increases photosynthesis (C3 crops) and reduces water use (C3 and C4). Yield increases of up to 70% have been observed
- Yield increases are higher when fertiliser is used
- FACE experiments show smaller yield increases than controlled environments

The effects of climate change on crops: experimental evidence

- Crop growth and yield will be enhanced by elevated CO_2
- … but, benefit could be less on farmer's fields
- Warmer seasons will be shorter and yields less
- … but, adaptation can counter this to some extent
- A few days of hot temperature can severely reduce yields
- Crops will be vulnerable to variability in rainfall
- These processes will interact, and the details matter

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

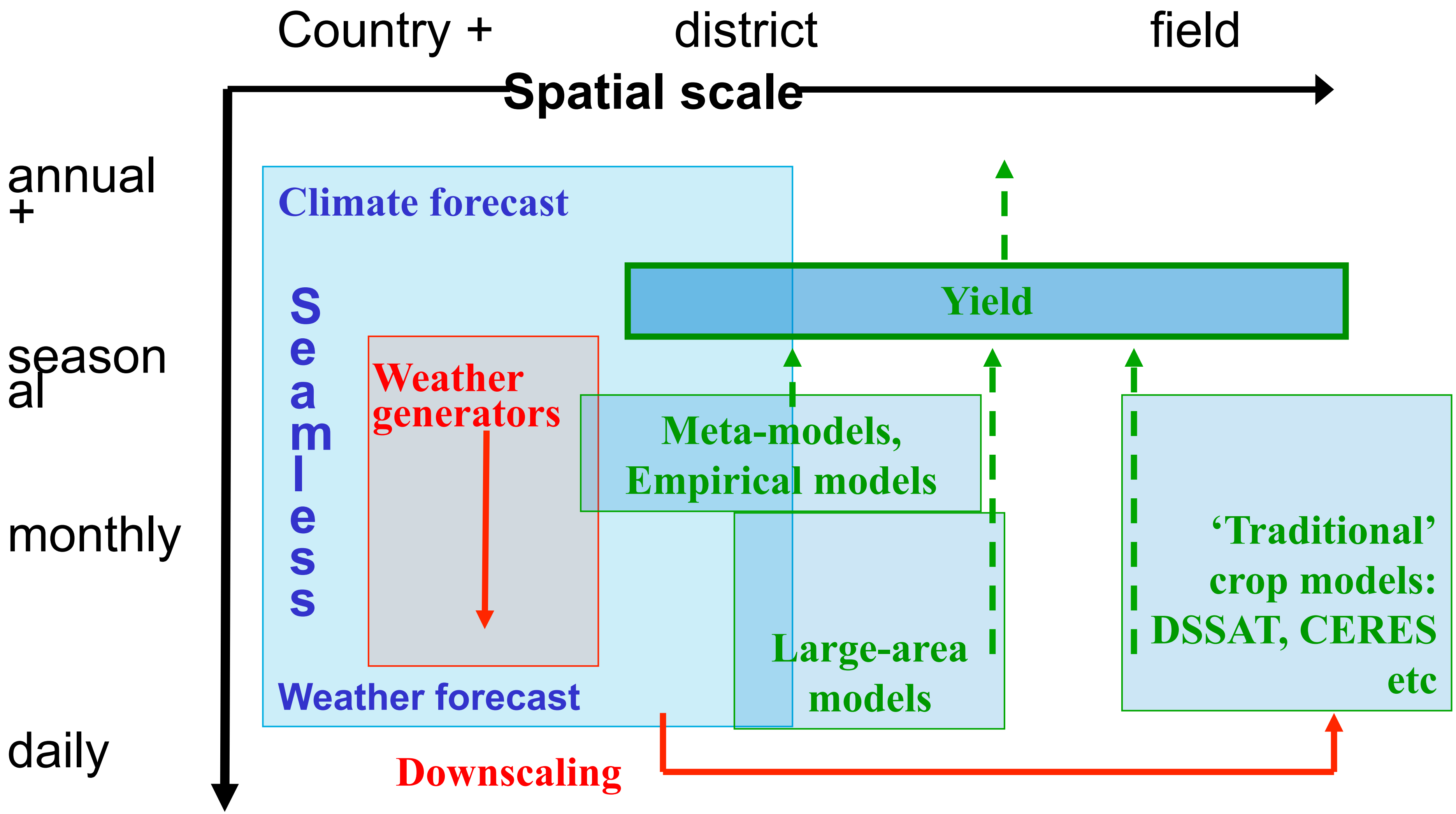
Process-based

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

⇒What is the appropriate level of complexity?

– Near to the yield-determining process on the spatial scale of interest (Sinclair and Seligman, 2000)

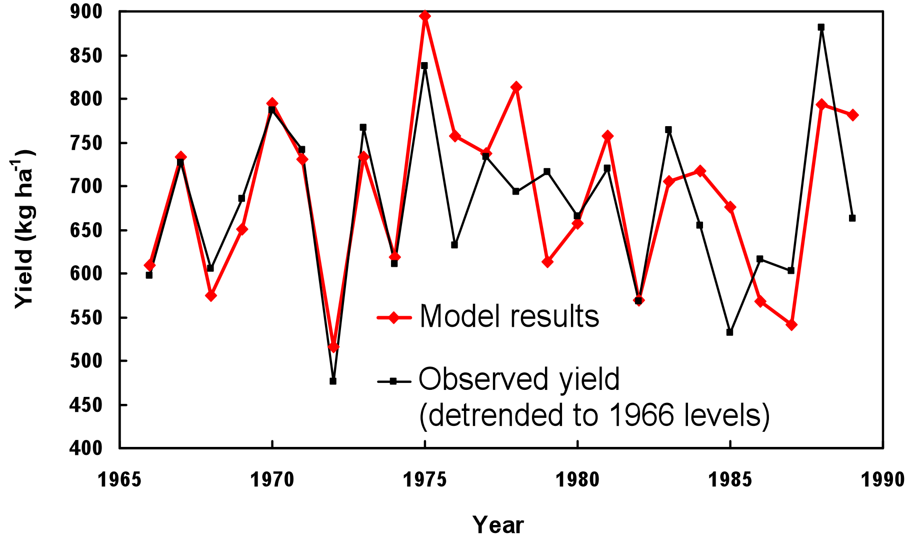
Combining crop and climate models



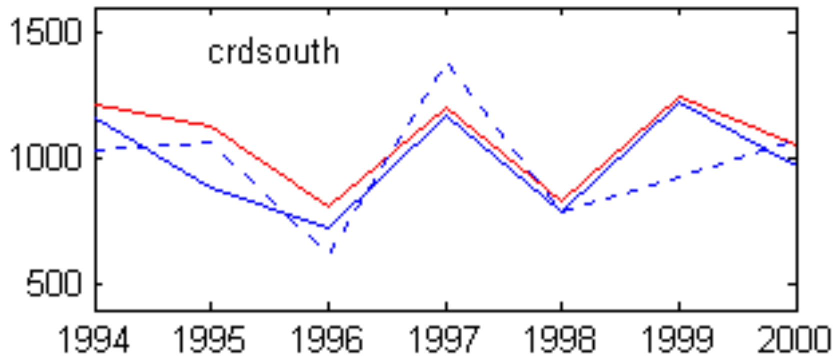
Modelling methods

- Climate model ensembles
- Process-based crop model designed for use with climate models
  - Focus on biophysical processes (abiotic stresses)

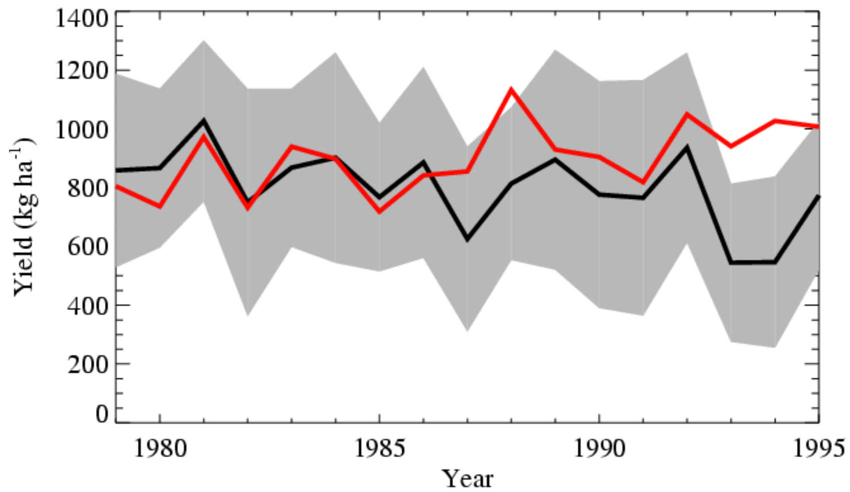
Challinor et al. (2004)



Chee-Kiat (2006)



Osborne (2004)



Seasonal forecasting of crop yield using climate model ensembles

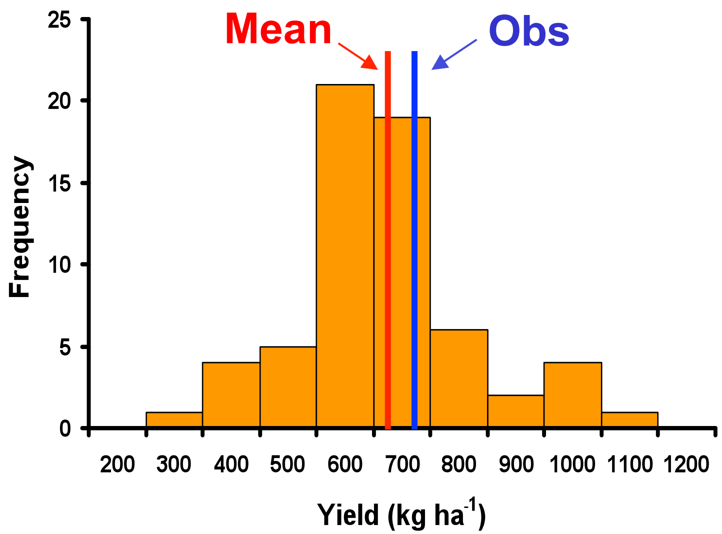
• Multi-model ensemble: 7 (models) * 9 ensemble members

• Run each seasonal hindcast realisation through GLAM to create an ensemble of crop yields

• Try various bias-correction and calibration options

Challinor et al. (2005c)

Probabilistic forecasting of crop failure



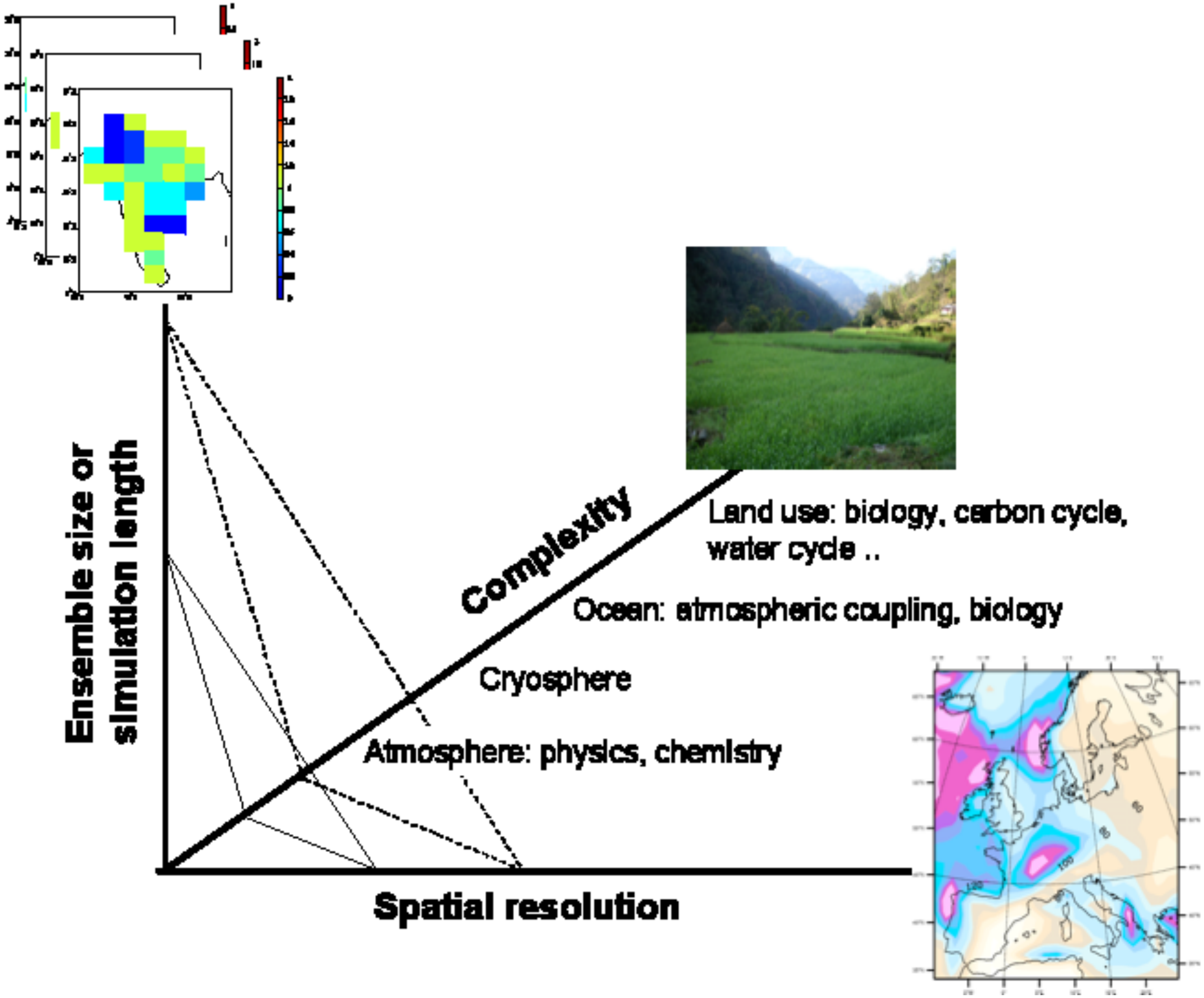
- The number of ensemble members predicting yield below a given threshold is an indication of probability of occurrence

- Found predictability in crop failure

- Less predictability in climatological yield terciles

Challinor et al. (2005c)

Computing strategy for impacts studies



Challinor et al. (2009b)

Overview

1. **Assessing future food production and food security**
   - Methods (yesterday)
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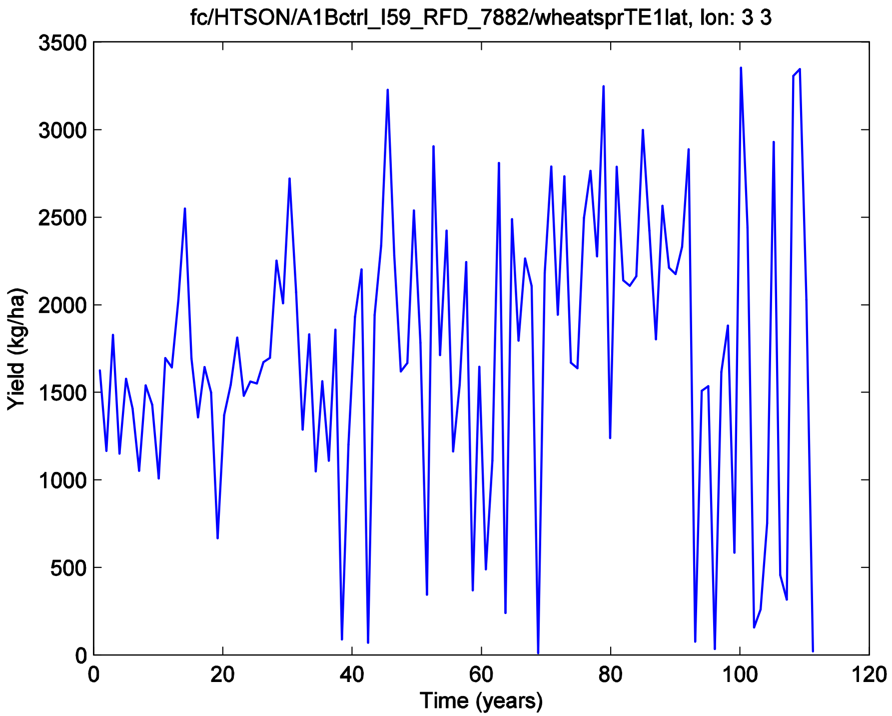
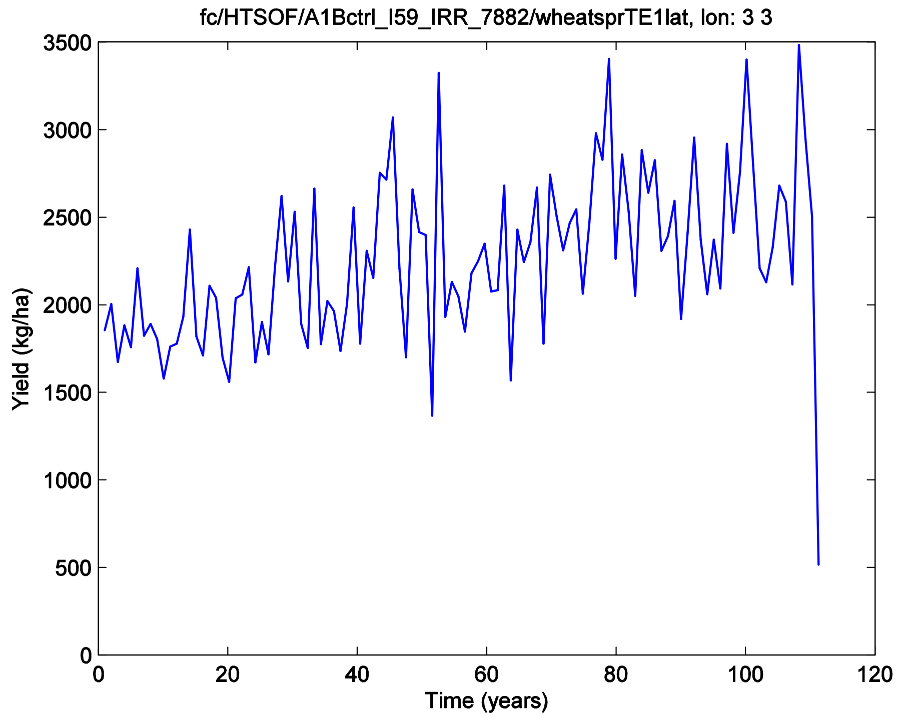
Temperature variability: thresholds

Photos: Tim Wheeler

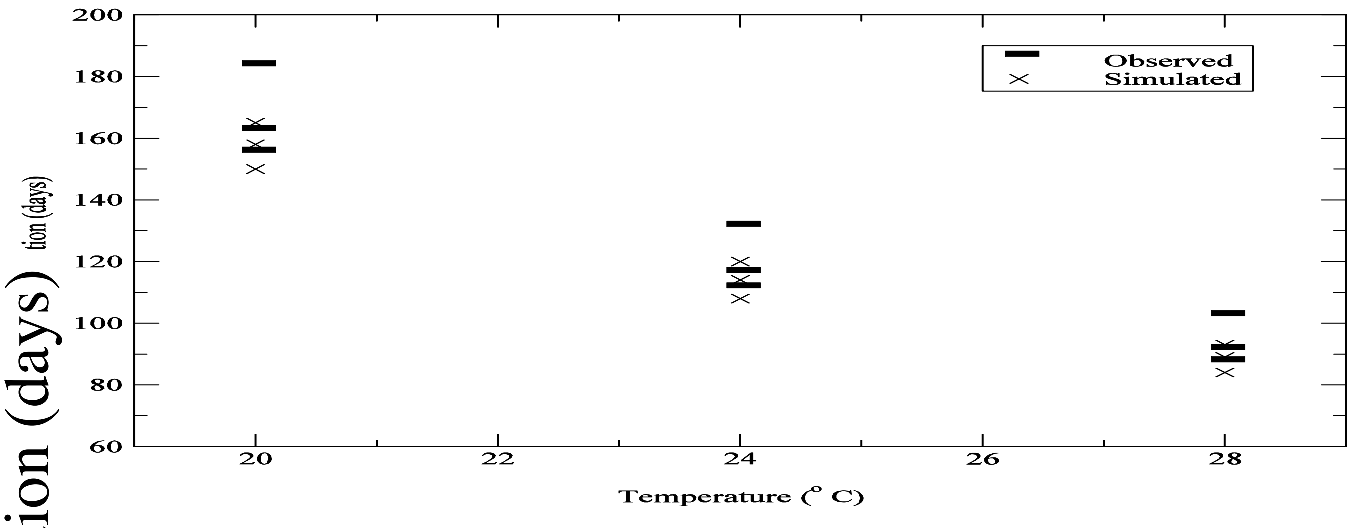
New crops for new climates?: the impact of extremes in China





Challinor et al. (2010)

The effect of changes in mean temperature



Duration (days)

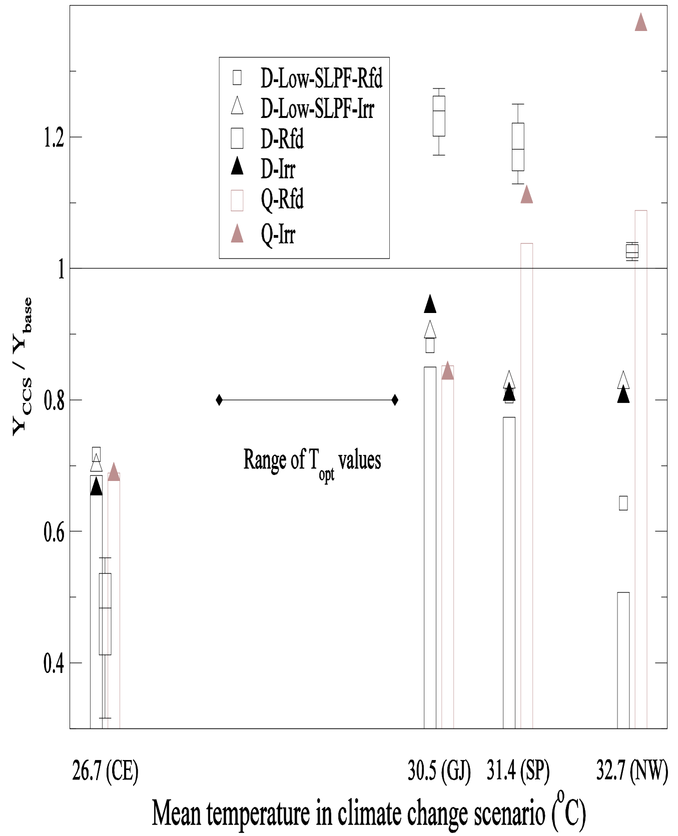
Mean temperature

Challinor et al. (2005a)

A leaky May and a warm June,

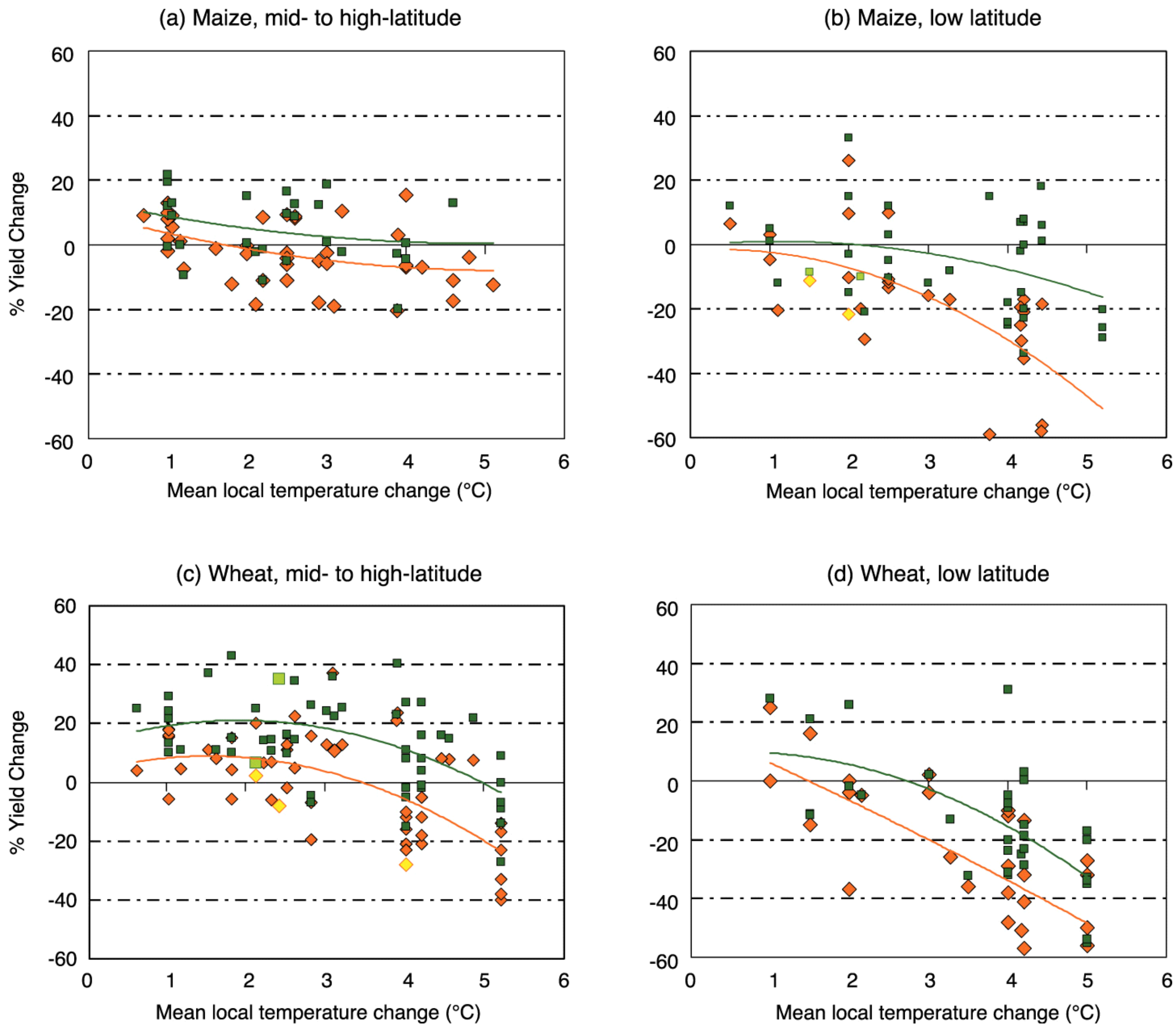
brings on the harvest very soon

Inter-model comparisons: response to mean temperature change



Challinor and
Wheeler (2008a)

Response of crops to warming: IPCC



Climate impacts Group

Overview

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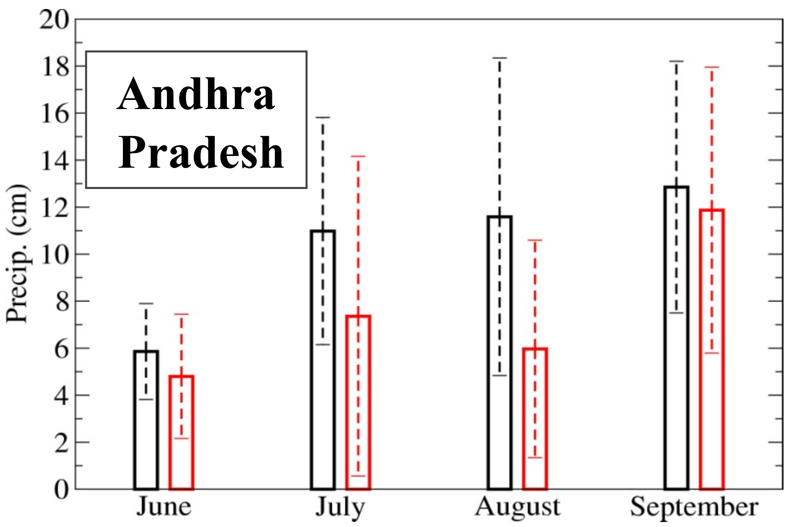
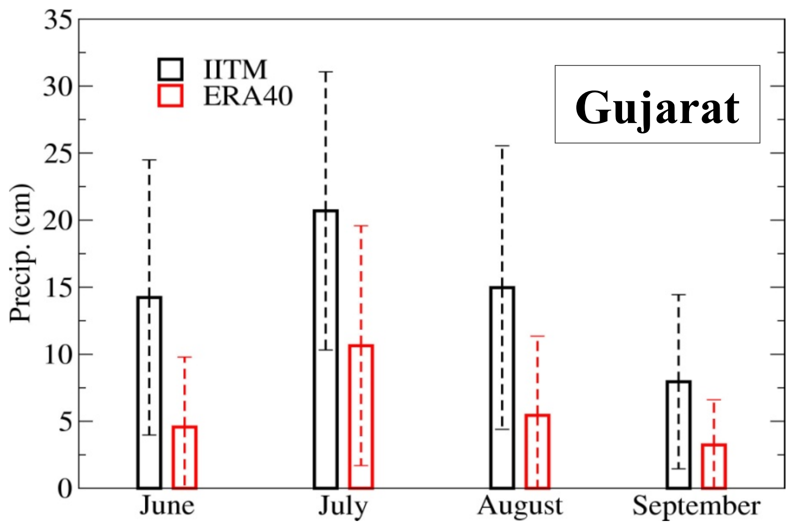
Sometimes uncertainty is avoidable e.g. by bias correcting climate model error



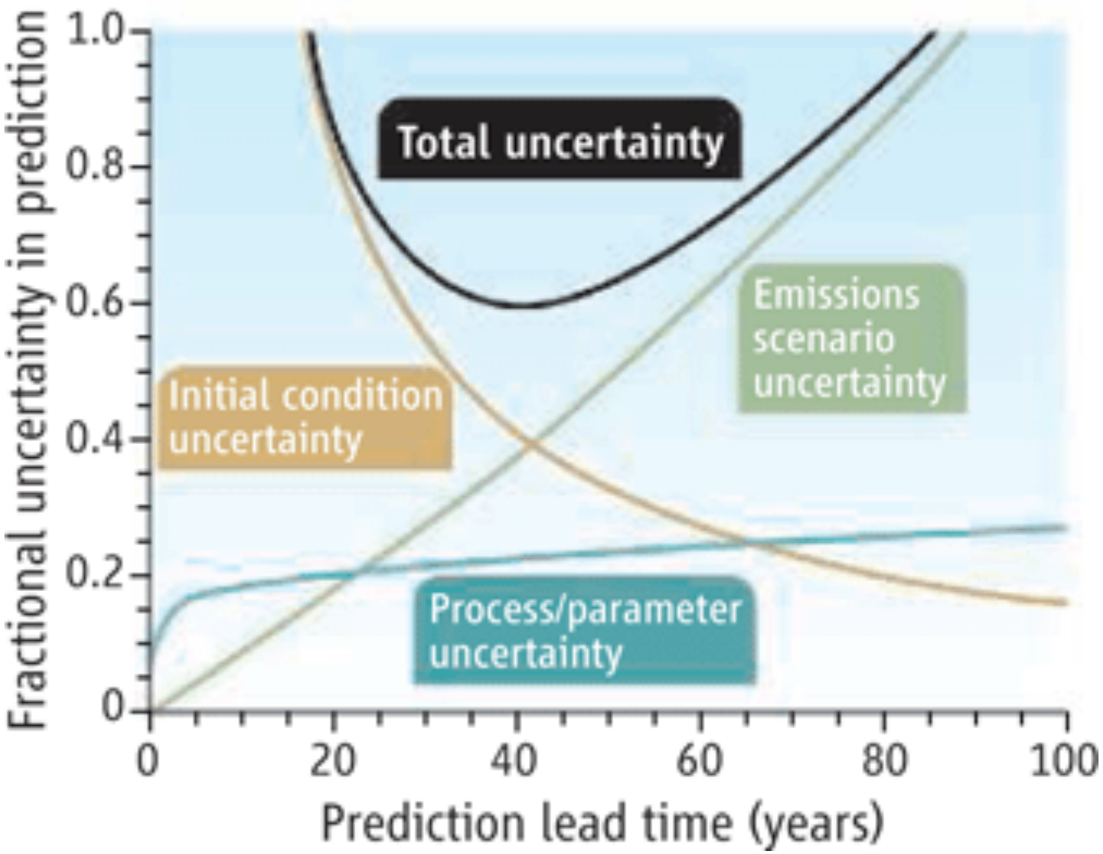


- Gujarat: bias correction of climatological mean rainfall works well
  - Correlation with observed yields 0.49 ➠ 0.60, mean yield rises, RMSE falls

- Andhra Pradesh: simulated mean yield < observed, variability >> observed
  - Incorrect seasonal cycle (both mean and variability) though Jun and Sept good.
  - This is harder to correct.

Challinor et al. (2005a)

How (un)certain are we?
… it depends how far ahead we look

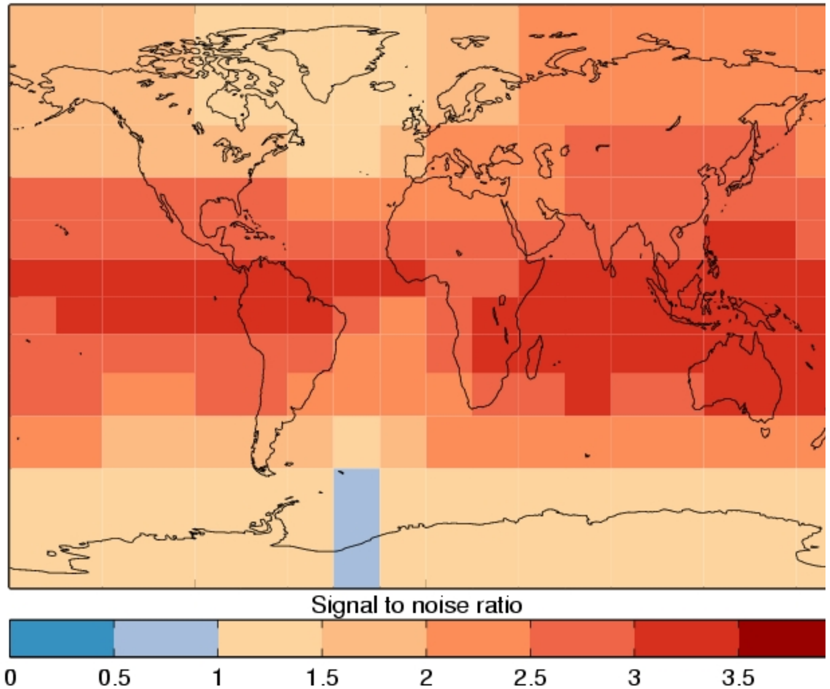


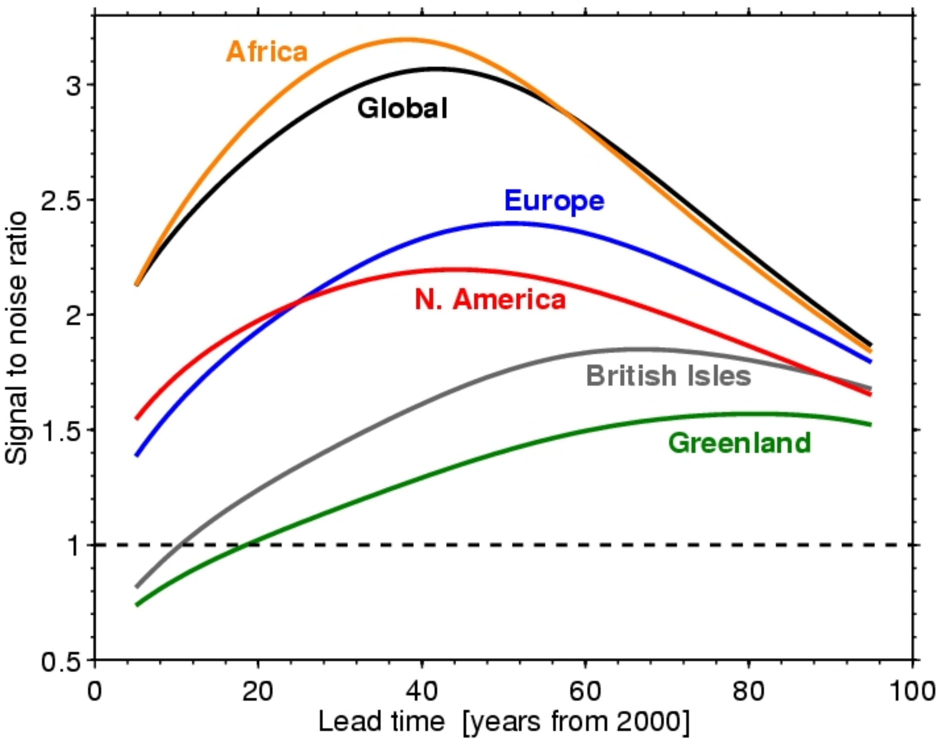
Climate predictions focusing on lead times of ~30 to 50 years have the lowest fractional uncertainty.

This schematic is based on simple modeling.

Cox and Stephenson (2007) Science 317, 207 - 208

… and where we look



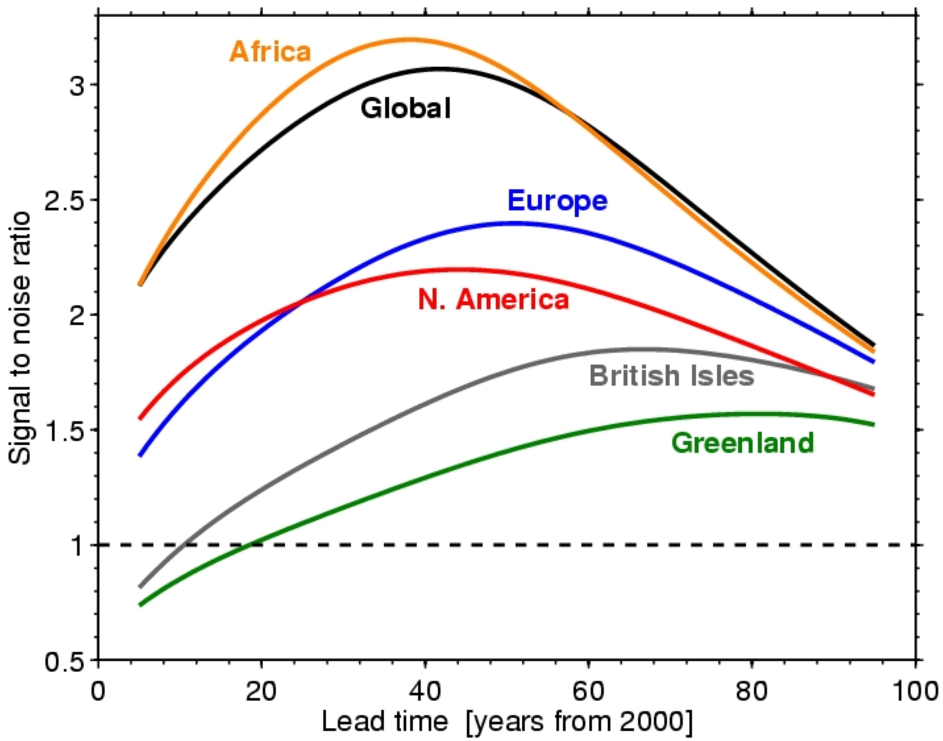


Signal to noise ratio for decadal mean surface air temperature predictions

Hawkins and Sutton (2009)

Predictability and uncertainty

Signal to noise ratio for decadal mean surface air temperature predictions



Hawkins and Sutton (2009)

What would these curves look like for impacts?

- Crops
- Health
- …

Improving treatment of uncertainties

www.equip.leeds.ac.uk

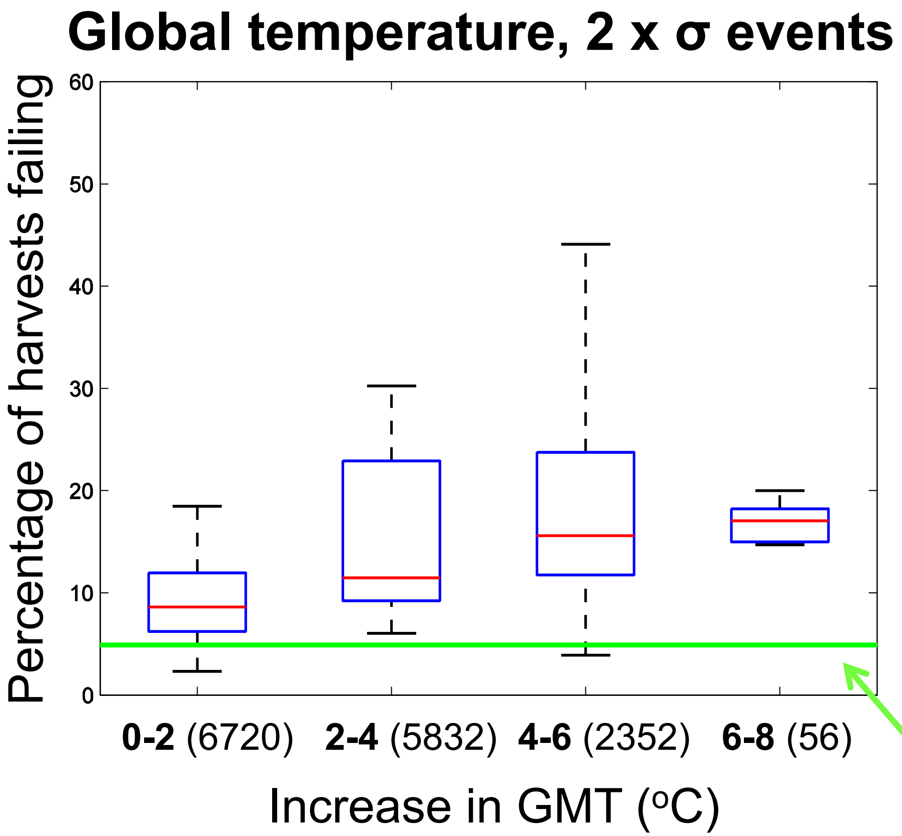
EQUIP

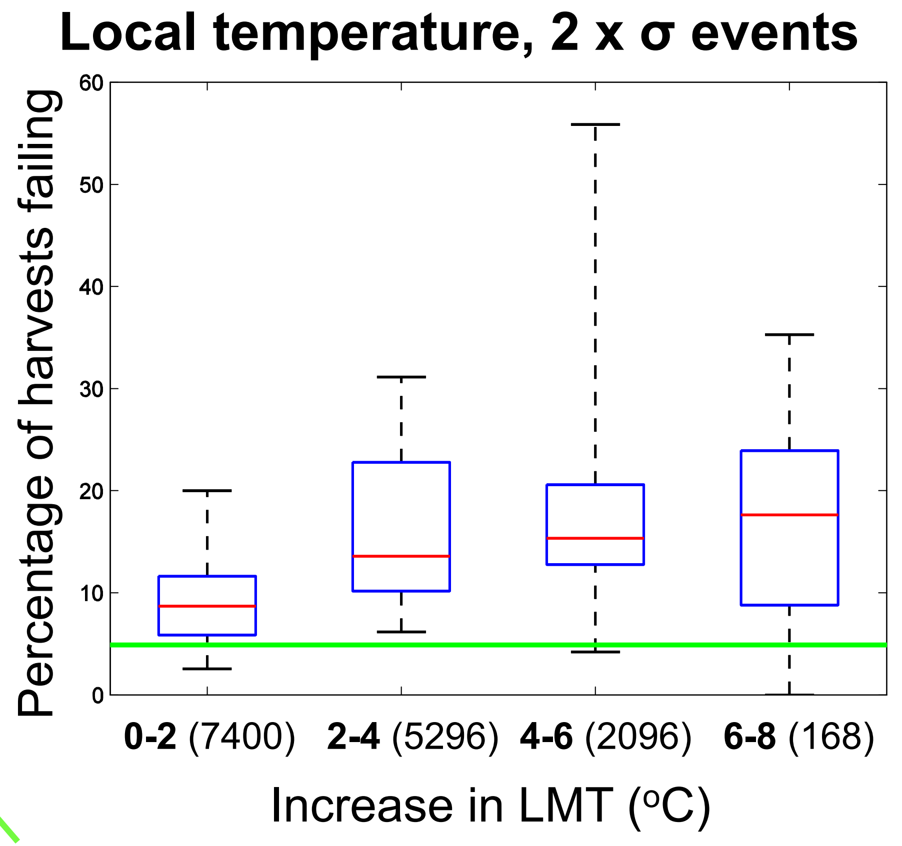
Brings together the UK climate modelling, statistical modelling, and impacts communities to work closely together for the first time to:

- Increate the utility of climate prediction: develop risk-based prediction systems for decision making
- Advance the science of uncertainty: integrated assessments of the cascade of uncertainty from climate to impacts (not just feeding climate ensembles through impact models)
- Develop new methodologies for assessing the information content of climate-model projections

	WP1 Design	WP2 Evaluation	WP3 Engagement
WP4 Implementation			
WP5 Crops			
WP6 Marine Environment			
WP7 Extremes			

Impacts as a function of global and local mean temperature change





Baseline failure rate

Challinor et al. (2010; ERL)

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Climate impacts Group

Overview

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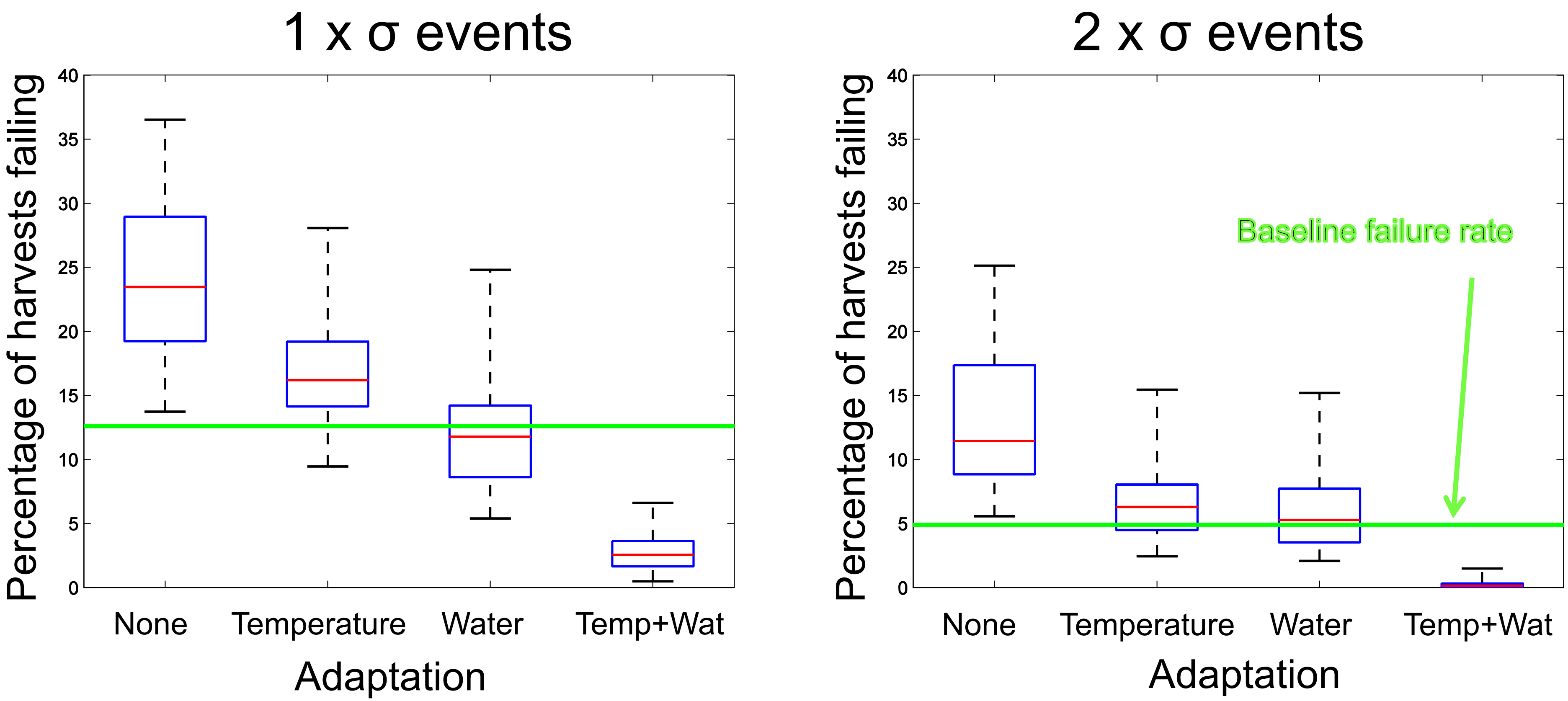
3. **Climate-resilient pathways and adaptation**

How should investment in adaptation be prioritised?



Challinor et al. (2010; ERL)

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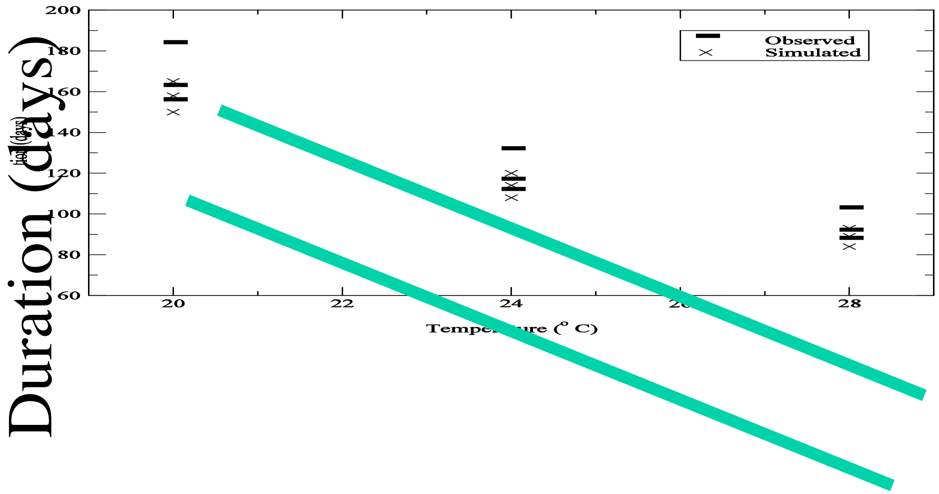
Do we have the real-world varieties to achieve adaptation?

Spring wheat in the northern US



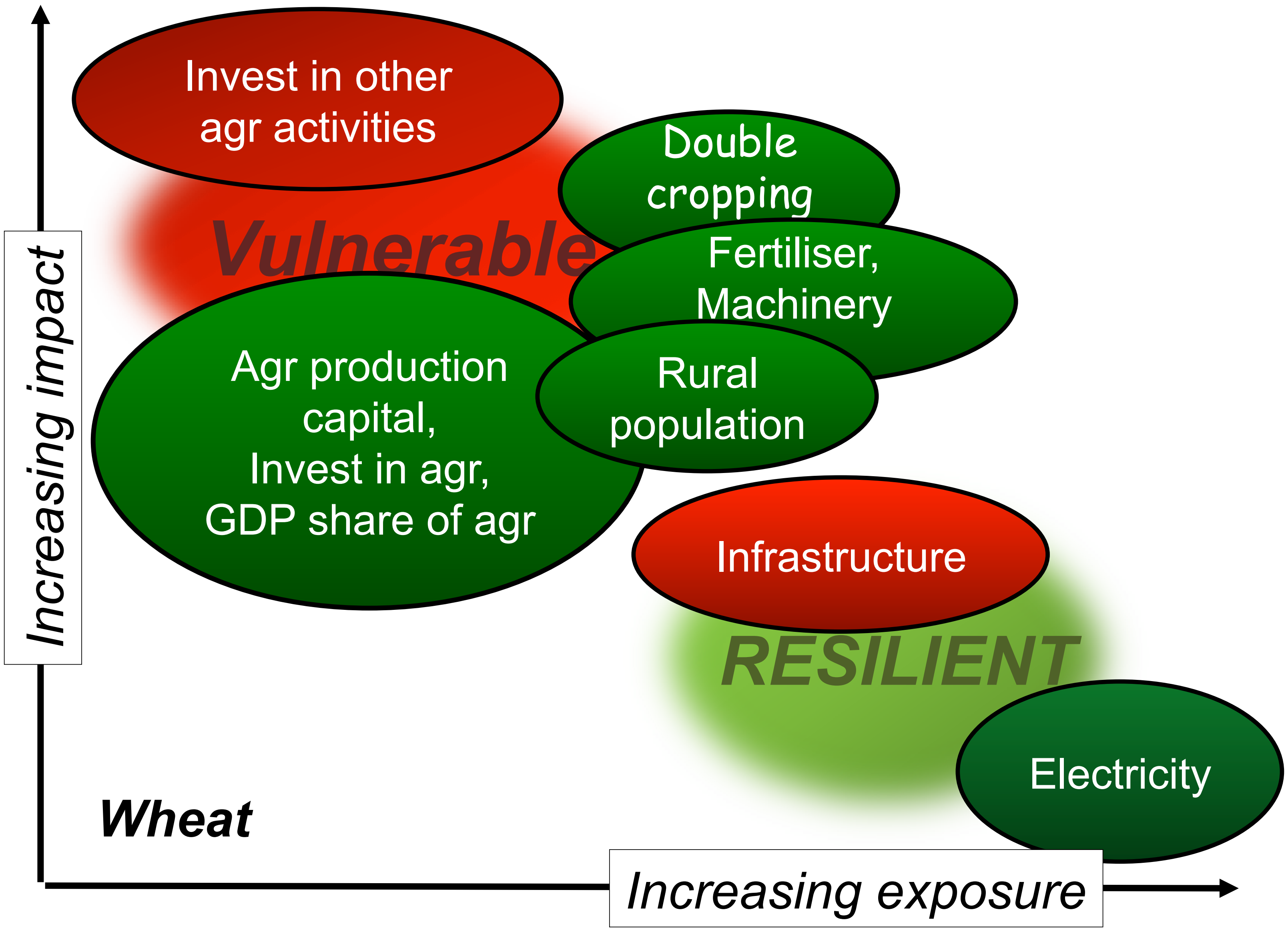
Mean temperature

Climate	Number of varieties suitable
+0°C	**87%** of all varieties **5** out of the top 5
+2°C	**68%** of all varieties **5** out of the top 5
+4°C	**54%** of all varieties **2** out of the top 5

Thornton et al. (in press)

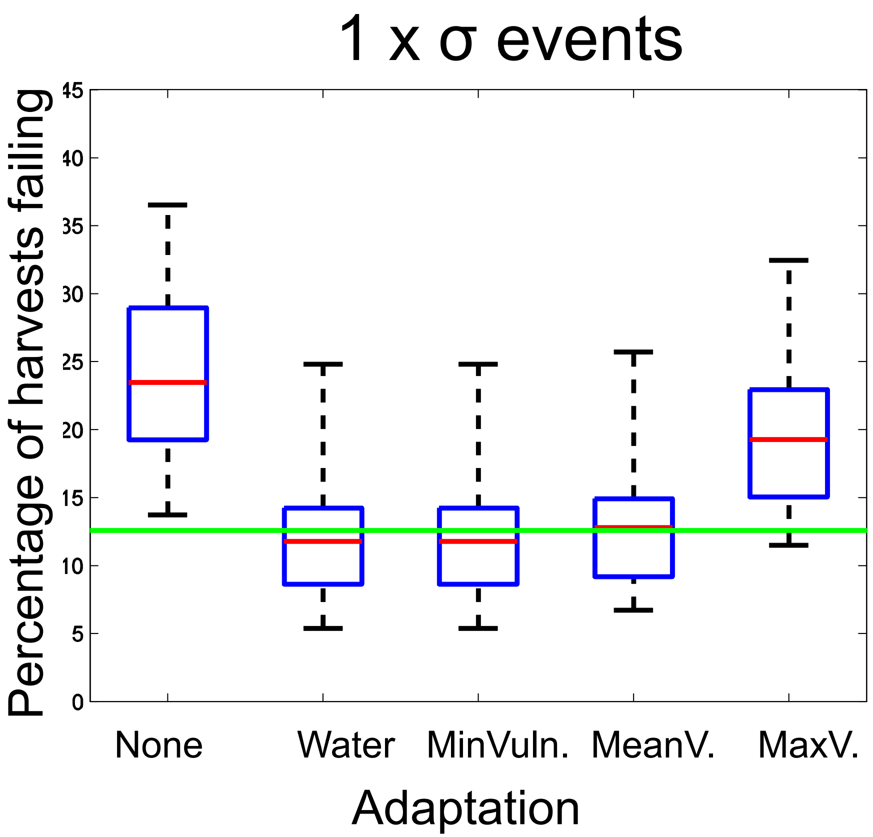
Svalbard
Global Seed Vault

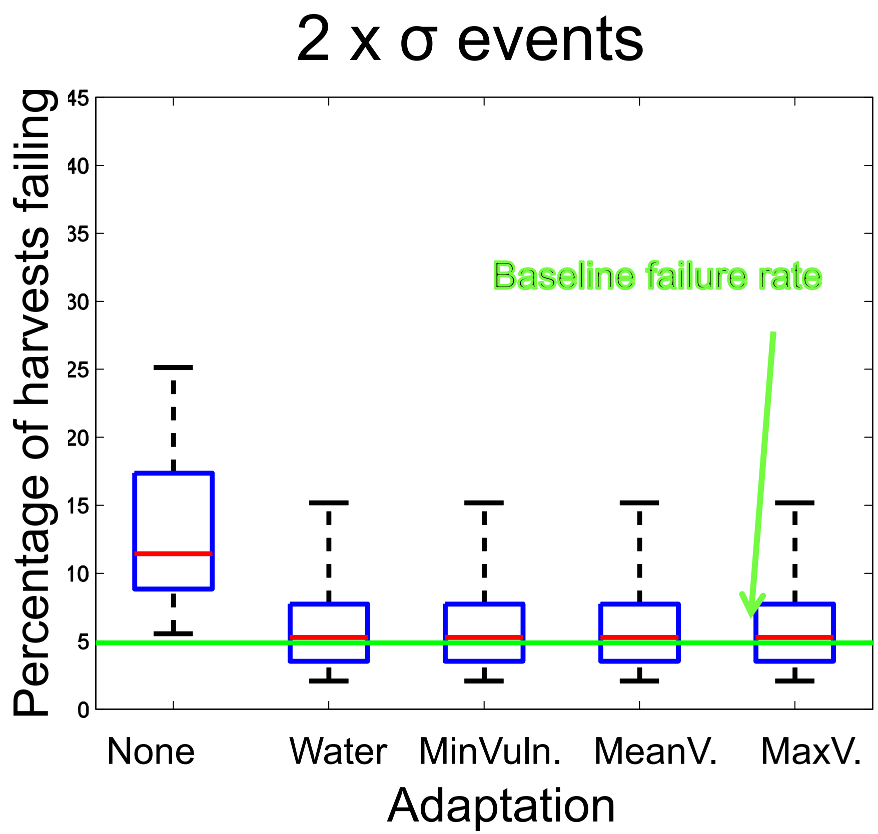
- Opened 26th Feb 2008
- $> 4 * 10^6$ samples
- -18 ^{o}C
- “Climate change proof”



Challenge: combining this understanding with the bio-physical crop modelling; see Challinor et al. (2009c)

How should investment in adaptation be prioritised: accounting for vulnerability





Challinor et al. (2010; ERL)

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Adaptation Pathways

Years: 100, 10, 1, 0.1, 0.01

- Climate change scenarios
- Near-term climate change, Decadal variability
- Interannual variability
- Seasonal cycle
- Sub-seasonal variability
- Weather

- Migration, large-scale infrastructure

Adapting to progressive change

- Breeding, strategic research, change of farming system

Adapting by managing risk

- Technology selection, resource allocation
- Field operations

CLIMATE CHANGE AGRICULTURE AND FOOD SECURITY

Alliance of the CGIAR Centers

Earth System Science Partnership

Overcome threats to food security, livelihoods, environment posed by climate change:

- Adapting agricultural development and food security policy to a changing climate.
- Assist farmers, policymakers, researchers and donors to continually monitor, assess and adjust their actions in response to observed and anticipated changes in climate.

Working in partnership:

- Co-proposed by CGIAR & ESSP
- New partnerships, science, interventions

Themes:

- Diagnosing vulnerability and analyzing opportunities
- Unlocking the potential of macro-level policies
- Enhancing researcher–stakeholder interactions
- Adaptation pathways based on managing current climate risk
- Adaptation pathways under progressive climate change
- Poverty alleviation through climate mitigation

The Africa College Partnership

- Partnerships with IITA and ICIPE and over 30 African national research institutions
- 100 members in Leeds and Africa
- Inspired individuals to work on real world problems
- Informed government and research council policy
- Developing new technologies for UK and Africa
- Global reputation on climate change and agriculture
- Increased interdisciplinary research and ideas (e.g. ESPA, food and transport, water

Impact Competition

Agriculture and health

Aflatoxins: highly toxic substances produced by the ubiquitous *Aspergillus* fungi in common staple crops

- Synergistic with Hepatitis B Virus to cause liver cancer
- Impairs growth and development of children
- Suppress immune system – increased susceptibility to diseases, e.g., HIV, malaria?
- Death (>200 people in Kenya)
- Trade impact -- >US$1.2 billion loss

RELIEF

Spoilt maize threatens schools food programme

By LUCAS BARASA

A school-feeding programme for 40,000 pupils in some of Nairob's slums has been thrown into disarray by contaminated relief food.

Hundreds of bags of yellow maize and peas donated by the US government and supplied by the World Food Programme (WFP) have been seized after samples from one of the schools were found to be contaminated.

Investigations have been launched to establish how the food became poisonous and at what stage in the process of supply and storage.

Yesterday, the WFP said all its food was always tested for aflatoxin and moisture content, among other things, before being handed over to the Ministry of Education.

"WFP is confident that no aflatoxin is present in any of the food provided by the organisation to WFP supported programmes in Kenya."

It attributed the possible contamination to "poor storage conditions and inadequate handling, particularly during the rainy season, as well as mixing of

CONTINUED ON PAGE 4

BBC NEWS WORLD EDITION

Last Updated: Sunday, 13 June, 2004, 12:33 GMT 13:33 UK

E-mail this to a friend   Printable version

Killer maize sparks Kenya alarm

Several Kenyan politicians have urged the government to declare a national disaster following the death of more than 80 people from contaminated maize.

Twenty-eights bags of poisoned maize were impounded at a girls' school in eastern Kenya on Saturday.

MPs from drought-prone Makueni, Kitui, Mwingi and Machakos districts warned that unless all poisoned maize was seized quickly, more people would die.

They also appealed for donations to set up a fund to help those affected.

"We demand action from the government since the lives of our people, especially in the arid areas, are at stake," Daudi Mwanzia, MP for Machakos town, said on the East African Standard newspaper website.

Health Minister Charity Ngilu was quoted last week as saying that 80% of locally available maize stocks were affected

Current research

UNIVERSITY OF LEEDS

Climate impacts Group

AFRICA COLLEGE Finding sustainable answers to hunger and malnutrition in Africa

EQUIP

CLIMATE CHANGE AGRICULTURE AND FOOD SECURITY

AgMIP

BBSRC bioscience for the future

NATURAL ENVIRONMENT RESEARCH COUNCIL

Insect pollinators initiative

Centre for Climate Change Economics and Policy

Agriculture & Health Research Platform

Acknowledgements

Elisabeth Simelton

Tom Osborne

Tim Benton

James Hansen

Tim Wheeler

David Green

Gordon Conway

Modelling strategies

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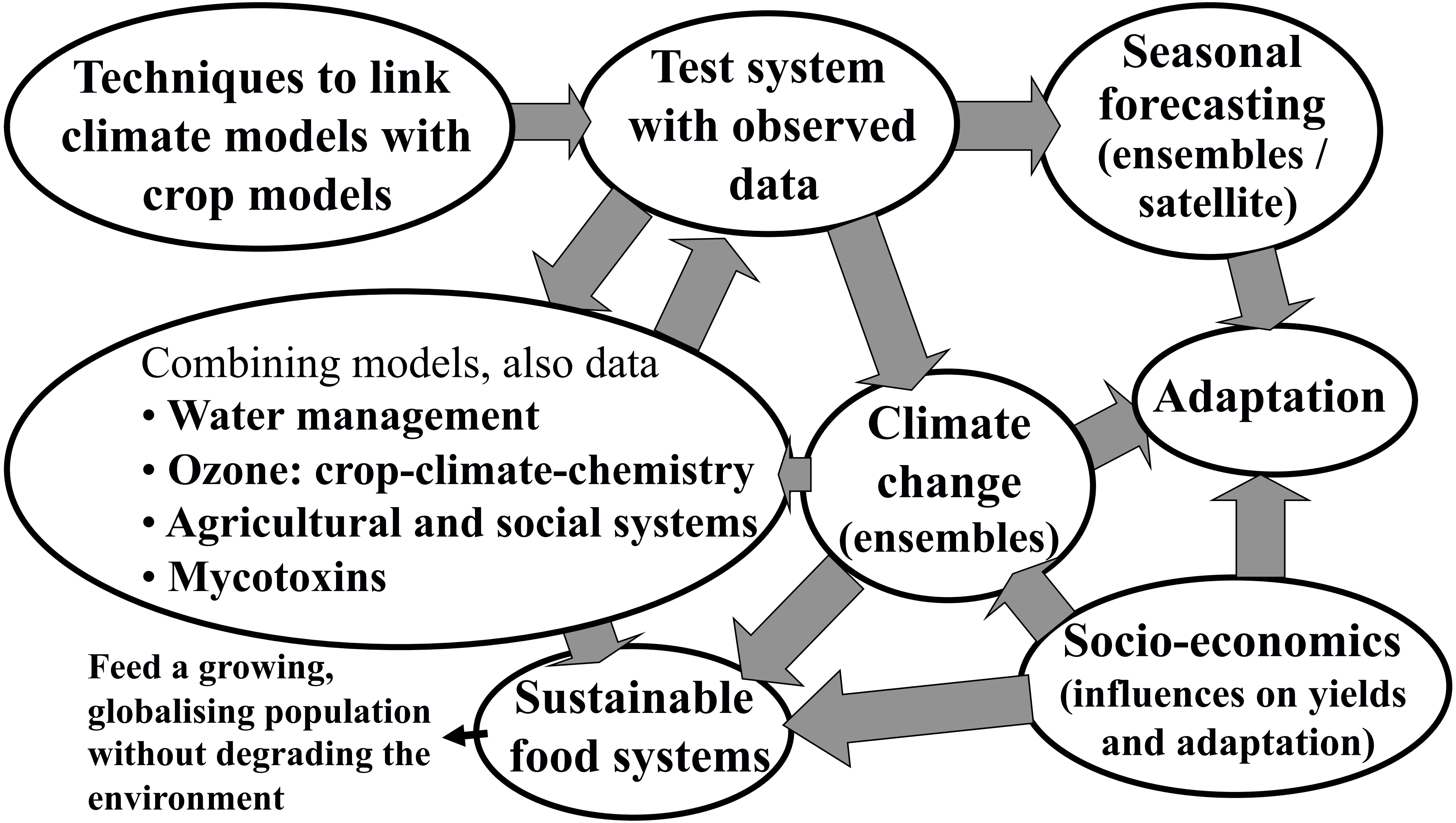


Large-area crop modelling

1. A basis in observed relationships.

- Correlate weather/climate and crop yield at range of scales (Challinor et al., 2003)
- Beware of assigning causality (e.g. Bakker et al., 2005)
  => need process-based modelling

2. Appropriate complexity.

- ↑ processes => ↑ interactions => ↑ potential for error. (See e.g. Monteith, 1996).
- Simulate at appropriate level of organisation – mechanisms near to the yield-determining processes should be simulated (Sinclair and Seligman, 2000)

3. High fraction of observable parameters.

- Parameterisations are then directly testable (e.g. dL/dt, TE)
- Reduces risk of over-tuning
- Semi-empirical approaches as well as processes-based.
  e.g. Potgeiter (2005) related a plant water stress index to yield

Interactions between water and CO_2

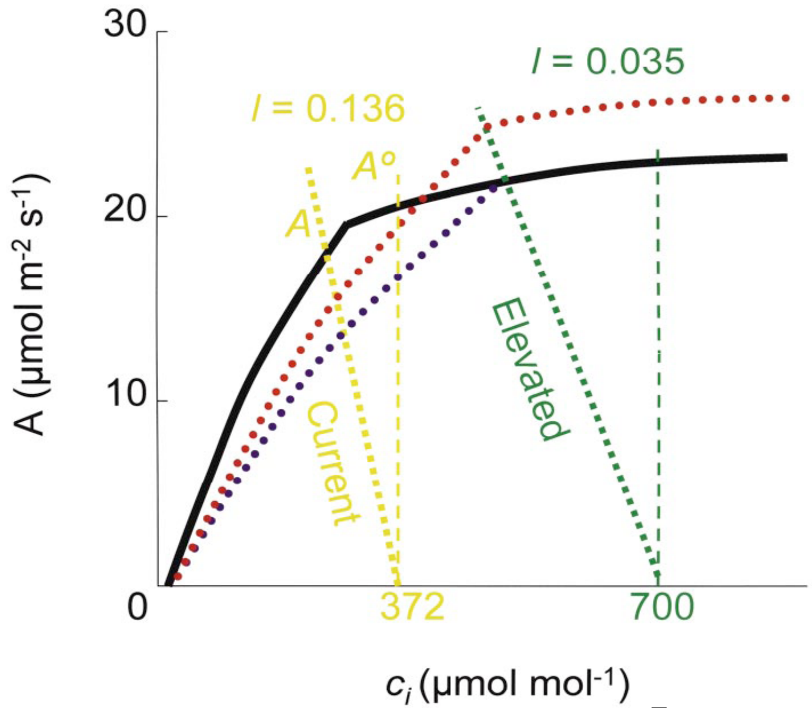
Standard wisdom:

"Droughted plants take better advantage of high CO_2 because they are at a point in the photosynthesis curve that is more CO2-sensitive." (TAR WGII)

What do

- Models
- FACE

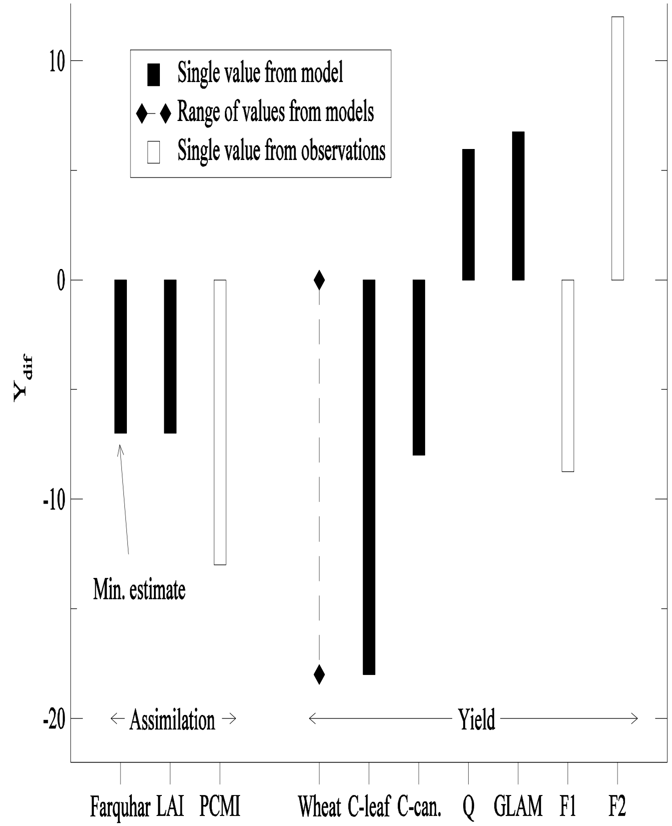
say?



Long, et al., 2004

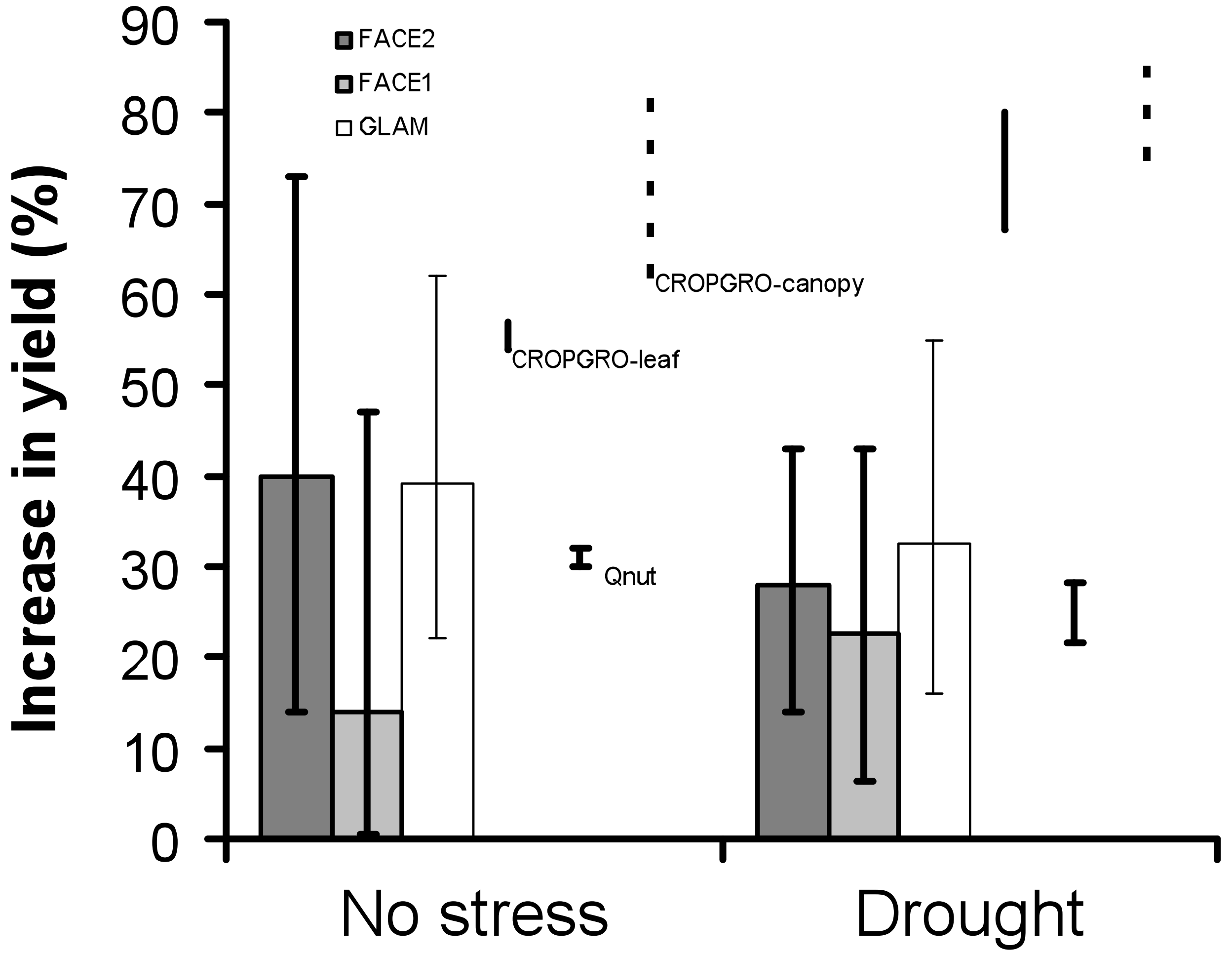
Interaction between water stress and assimilation

y: yield change for well-watered crop (%) minus yield change for stressed crop (%)
x-axis shows, roughly, increasing level of organisation from left to right



Challinor and
Wheeler (2008b)

Interaction between water stress and assimilation



Crops and atmospheric composition: O_3

• Industrial emissions resulting in increased surface ozone are predicted to rise.

• Predictions for China particularly high.

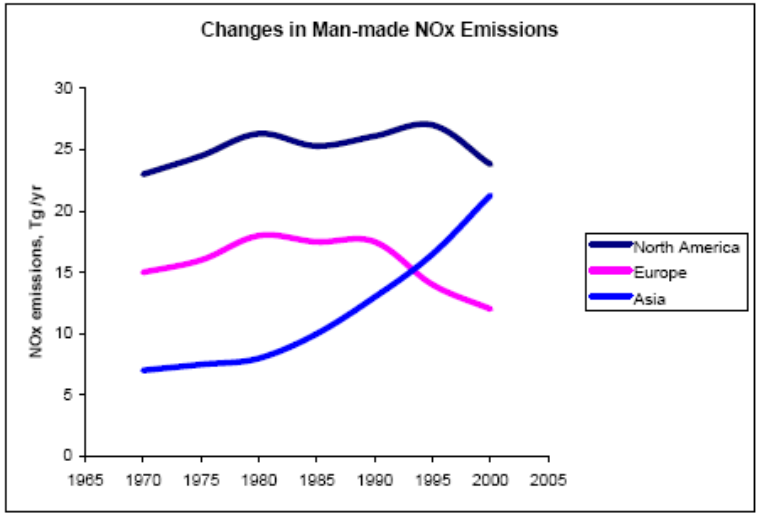


Figure 7: The development in man-made NO_x emissions from North America, Europe and Asia during 1970-2000.

• Ozone lowers the photosynthetic rate and accelerates leaf senescence
  - ~5% yield reductions currently; 30% in 2050?

• Few crop field studies with O_3 carried out in the tropics

See e.g. Long et al. (2005); Slingo et al. (2005); Royal Society (2008)

Current treatments of uncertainty

2 x CO_2 N. America	Wheat	-100 to +234%	Reilly and Schimmelpfennig, 1999
2080s Africa	Cereals	-10 to +3%	Parry et al., 1999
+4^{o}C local ΔT 'low latitude'	Wheat	-60 to +30%	IPCC AR4, chap. 5 (Easterling et al., 2007)
+4^{o}C local ΔT 'mid- to high-latitude'	Wheat	-30 to +40%	IPCC AR4, chap. 5 (Easterling et al., 2007)

See Challinor et al. (2007a)

Thinking further ahead: which varieties will still be suitable?

Spring wheat in the northern US

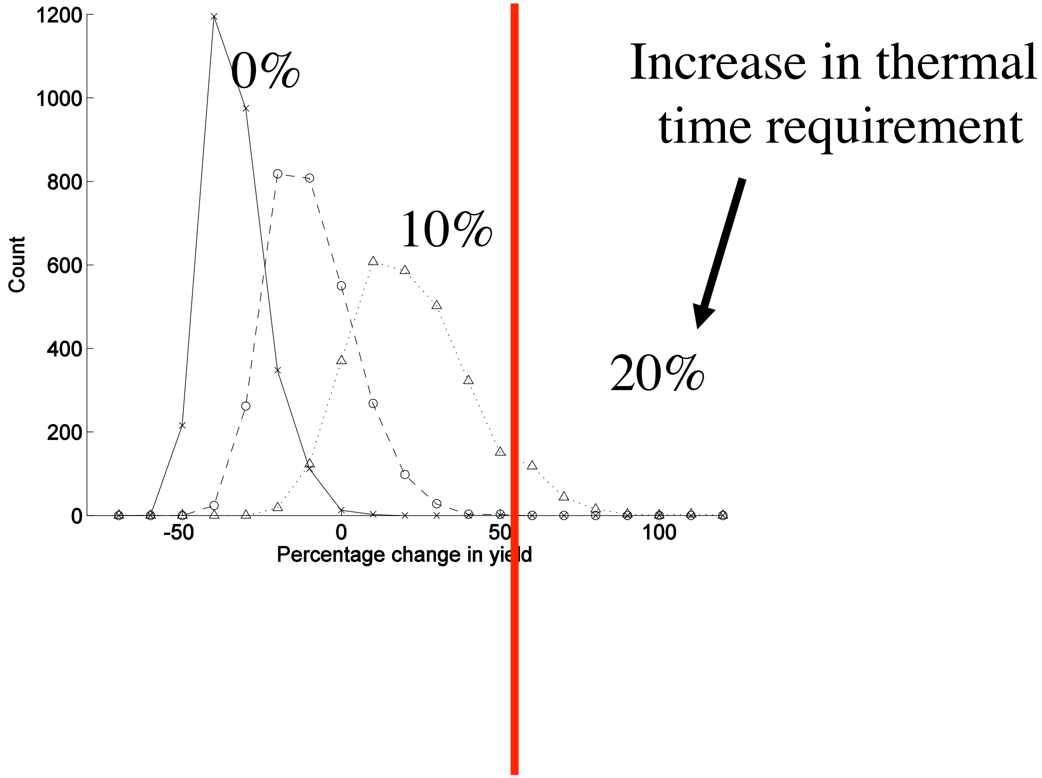
- Use crop data for spring wheat varieties from the CIMMYT database (6,229 trials, 2711 varieties)
- Use Thermal Time Requirement analysis of Challinor et al. (2009a) to assess the duration of these varieties
- Assume T<Topt (i.e. worst-case scenario) and define suitability as observed current-climate duration of 121 days

Climate	Number of varieties suitable
+0°C	**87%** of all varieties **5** out of the top 5
+2°C	**68%** of all varieties **5** out of the top 5
+4°C	**54%** of all varieties **2** out of the top 5

Adaptation options for one location in India

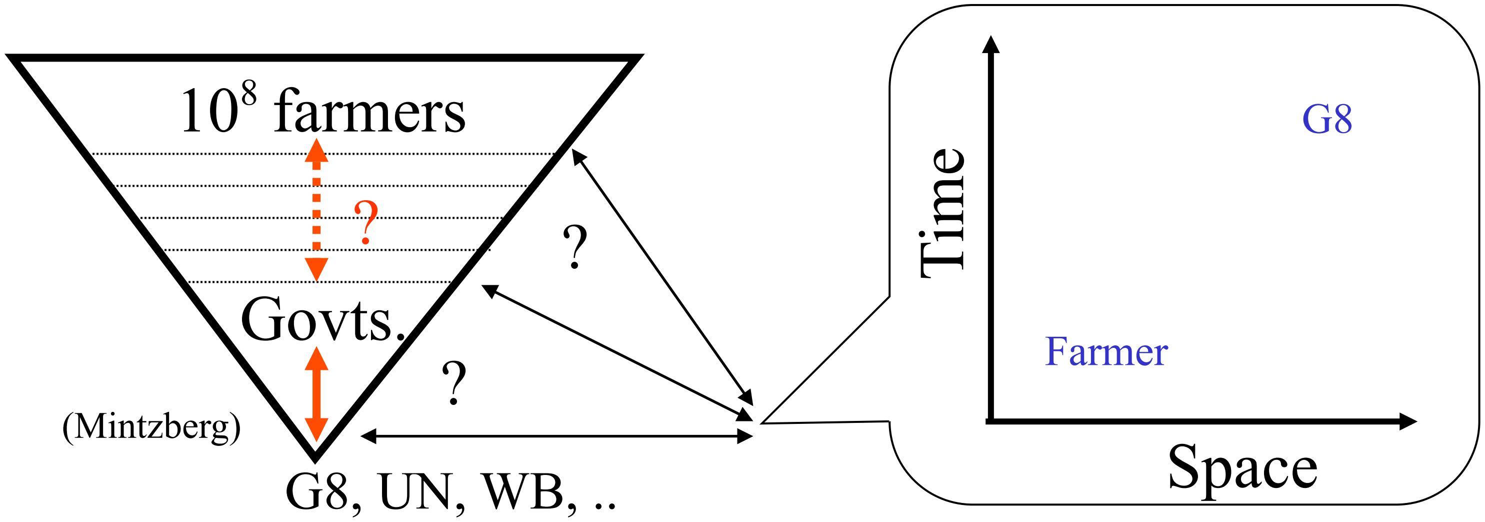
180,000+ crop simulations, varying both climate (QUMP) and crop response to doubled CO2

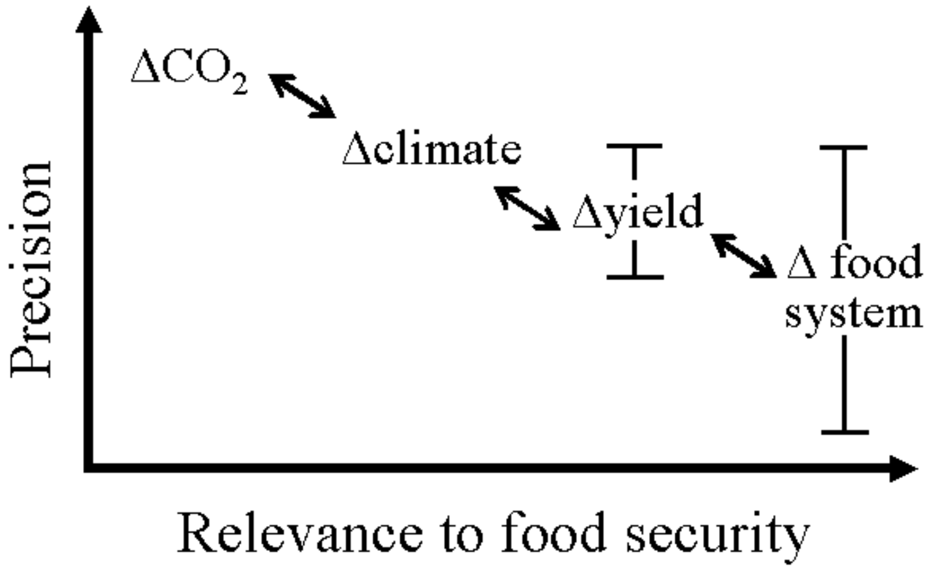
- Further simulations and analysis of crop cardinal temperatures suggest a **30% increase may be needed**
- Field experiments suggest the potential for a **14 to 40% increase within current germplasm**
- Suggests some capacity for adaptation



QUMP53

Challinor et al. (2009a)





Challinor (2009)

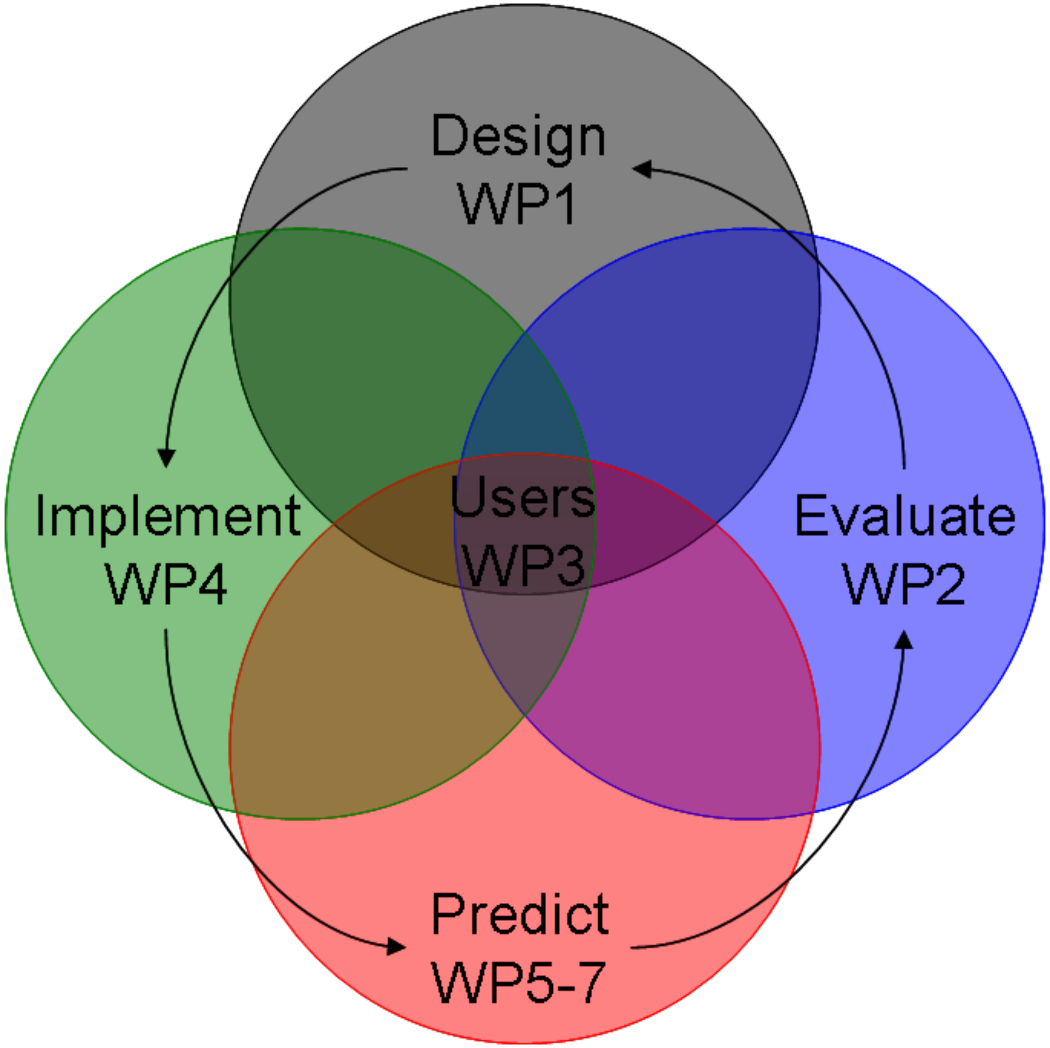
Lots of interconnected issues, e.g.

- **Pathways of information**
- **Influence of farmer on crop production through land use change and crop management**
- **Interactions between natural and social systems**
- **Access to seed for genotypic adaptation**
- **Perception of risk and uncertainty**

Research Questions

1) Is the skill in seasonal weather forecasting in West Africa sufficient to **predict the occurrence of high aflatoxin concentrations in groundnut?** If so, what methods can be used to maximise the capacity for prediction?
2) Does the known link between weather and aflatoxin result in a robust demonstrable **relationship between weather and aflatoxin concentrations, both in crops and in blood of exposed people?**
3) What decisions, informed by seasonal forecasting, can be made before and during the season to **minimise aflatoxin contamination**?

EQUIP structure



The EQUIP network

We are developing a network of academics and practitioners with an interest in predicting climate and its impacts in order to support decision-making and equip society for climate change.

For more details about EQUIP, including our conferences and information on how to join our network, visit www.equip.leeds.ac.uk

Project overview

Improving the use of climate prediction by quantifying, understanding and managing uncertainty.

Through working with stakeholders, the EQUIP team will develop new methodologies and analyses for using climate information that will be employed by decision makers in a set of case studies.

We will quantify and understand the uncertainty surrounding future droughts, heatwaves, crop production and marine ecosystems.

Aims and concepts

EQUIP: Improving the quantification, understanding and management of the uncertainties associated with climate predictions.

- Increase utility of climate prediction
  - Quantification of uncertainty
  - Including impacts
  - Predictability, relationship to spatial scale
- Advance the science of uncertainty
  - Cascade of uncertainty from climate to impacts
  - Relationship to model error and predictability
  - Model evaluation and past observations
- Grow community of scientists and users
  - Across disciplines
  - User engagement in our three key impacts and beyond
  - Make data and methods available

Tangible goals

- Develop new methodologies and analyses that will be cited in AR5 and/or employed by users
- Quantify and understand the uncertainty surrounding future droughts, heat-waves, crop production and marine ecosystems.
- Demonstrate the utility of our results by providing guidance to decision makers in a set of case studies.
  - e.g. ‘breeding crops for 2030’
- Train project researchers and promote project outcomes to influence practice, policy and research.
  - Metrics e.g. EQUIP network membership, user engagement, publications, conference presentations

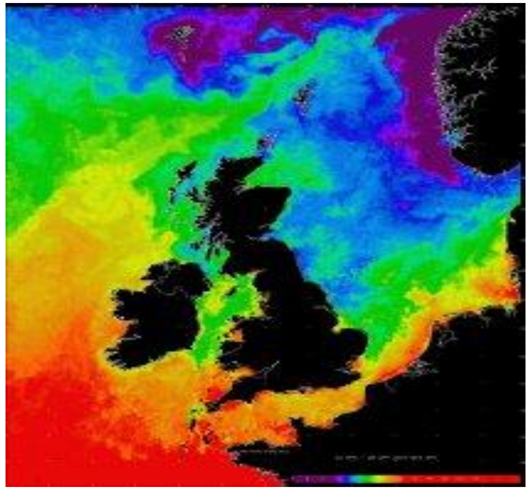
Targeted and informative forecast system design

Role of WP: to work directly with users and with other WPs to develop new approaches to the design of ensemble prediction systems that focus on information content and utility.

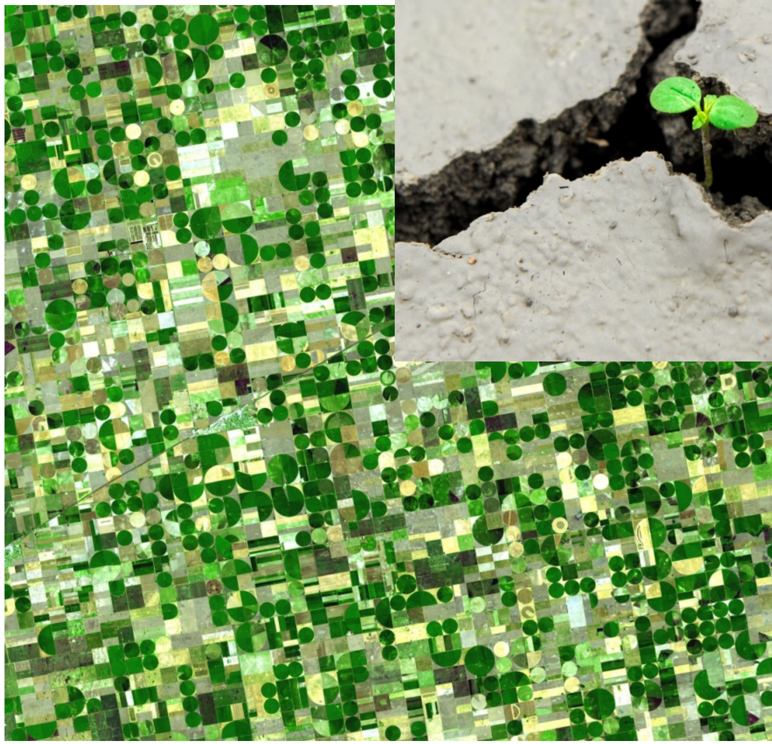
- New methods for determining the decision-relevant information content of climate models in a variety of user-determined applications.
- New methods for using models to support decision making in user-determined applications.

EQUIP

Design, implementation and evaluation of forecast systems needs to include user needs, and the relevant climate impacts, from the start.



- Marine ecosystems
- Crops
- Droughts
- Heatwaves
- Floods



NATURAL
ENVIRONMENT
RESEARCH COUNCIL

EQUIP

First user meeting

Purpose of workshop:

Identify active collaborators/users for EQUIP

To ensure that the EQUIP research agenda is appropriate for informing the decision making of target users.

Through conversation with invited users from the public, private and charity sectors, we will orient EQUIP towards improved use of climate information for specific cases.

First user meeting

Representatives from:

- Munich Re
- UK Met Office
- Environment Agency
- UK Department of Health
- Consultative Group on International Agricultural Research
- UK Climate Impacts Programme

Collaborative case studies initiated on:

- Case study on Heat and cold waves and links to health
- Crops for 2030
- UK water resources

Emerging issues

How the end to end analyses are carried out: Various options, e.g.

- Climate diagnostics or response surfaces sent to user
- Full end-to-end analysis using model chains, with summarised outputs
- Which approach is taken depends on the aim, e.g. specific decision or learning process ('storylines').

Treatments of uncertainty can help or hinder decision-making.

- *Amplifying c*ascades of uncertainty need to be decomposed or condensed in order to affect a decision
- Choice of language is important: uncertainty vs robustness vs risk

The multiplicity of sources of climate information causes problems, e.g. are they all to be treated as equally plausible?

Only sustained and informed engagement with users are likely to improve the utility of climate information.

Outcomes from first user meeting

e.g. Heat and cold wave case studies: health

Impact and decisions	Location	Timeframe	Current metrics	Proposed metrics
Cold waves Broken legs/hips strongly related to icy roads/cold spells Provision and training of orthopaedic services to be planned	SE England in first instance (other regions later)	>5 < 25 years	Counts of daily Tmin below 0 degC NHS stats?	1. Counts of Tmin<0 2. And Tmax >0 causing melt/ ice
Heat waves Mortality in the community and hospital admissions Indirect: building regs, air con (also useful for crops?)	SEE and Europe	<10 as adaptation takes place on longer scales?	CET? Many studies	1. 5-day mean T 2. 2. 2-day mean T 3. 3 days>29 and Tmin>17
Seasonal temperatures start/end of influenza season depends on mean temperature (also useful for crops?)	SEE	10-20	CET? Any studies?	Dates of 5-day mean temp crossing thresholds

Evaluation

We aim to provide users of climate predictions with quantitative information about decision-relevant aspects of expected performance...

... by combining expert judgments with detailed statistical analyses of forecasts and hindcasts of past weather, climate and climate impacts.

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