University of Leeds, 25th November 2014

Met Office
Hadley Centre

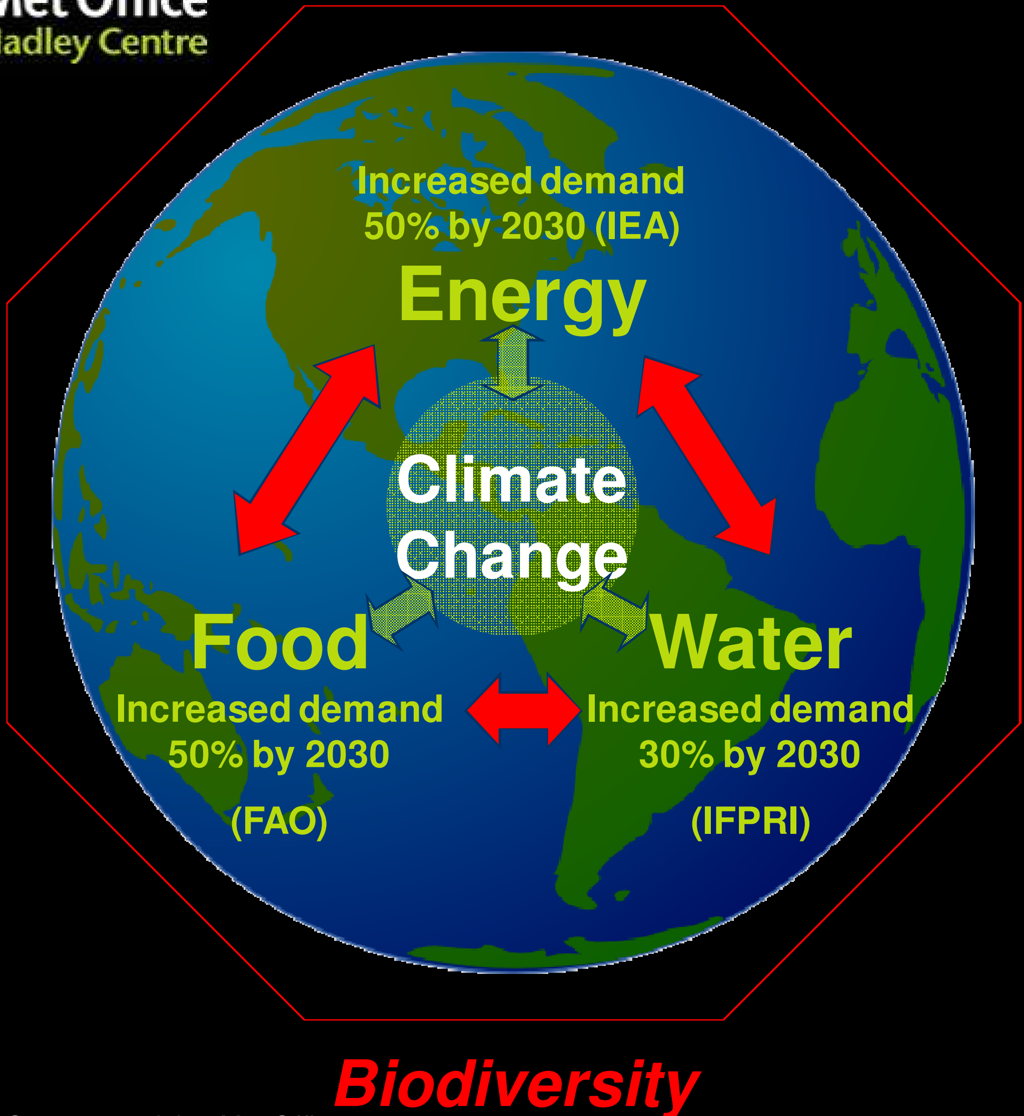
# Climate science for agricultural services:

## Challenges and opportunities

**Dr Pete Falloon**
pete.falloon@metoffice.gov.uk

# The perfect storm?

(John Beddington, 2009)




1. Can 9 billion people be fed equitably, healthily and sustainably?
2. Can we cope with the future demands on water?
3. Can we provide enough energy to supply the growing population coming out of poverty?
4. Can we mitigate and adapt to climate change?
5. Can we do all this in the context of redressing the decline in biodiversity and preserving ecosystems?

# Outline

- Key challenges in climate science for agriculture and water:
  - Unrealised potential in models and metrics relevant to agricultural policy and business outcomes.
  - What do wide uncertainty ranges in current impact assessments mean for decision making and policy?
  - Poor uptake of seasonal forecasts, particularly in Europe
  - Inadequate information on future impacts of extreme weather events on agricultural systems at small spatial scales
  - Poor understanding of linkages between overlapping priorities for land and water in a changing climate
- Summary & other key issues

# Improving models & metrics : more relevant agricultural science for policy and business

**Some of the issues:**

- Delay between providing climate scenarios and impact assessments
- Standard outputs of climate models not relevant
- Fundamental issues with general crop/water models
- Need to understand crop-water-climate interactions

# The traditional approach delays provision of impact assessments

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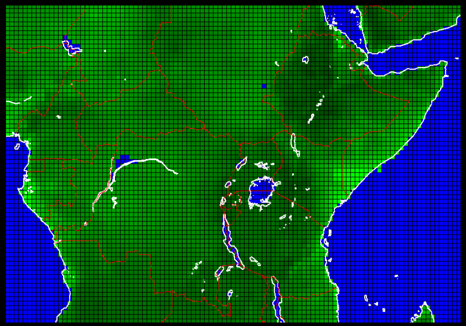
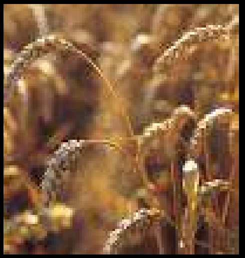
Global Climate Model



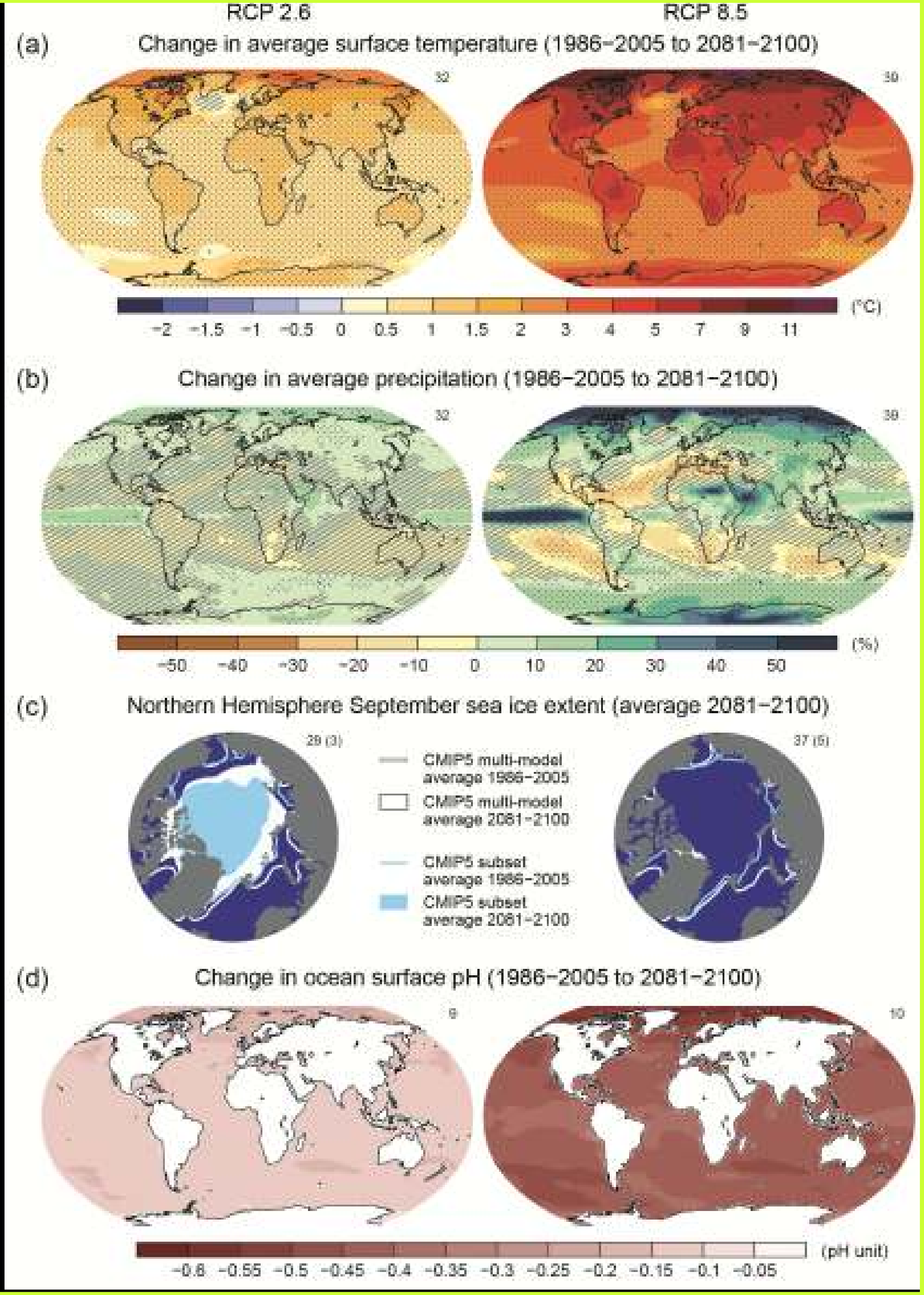
Regional Climate Model



Impacts Models

# Standard outputs of climate models: relevant to agriculture?

*(IPCC WG1, 2014)*



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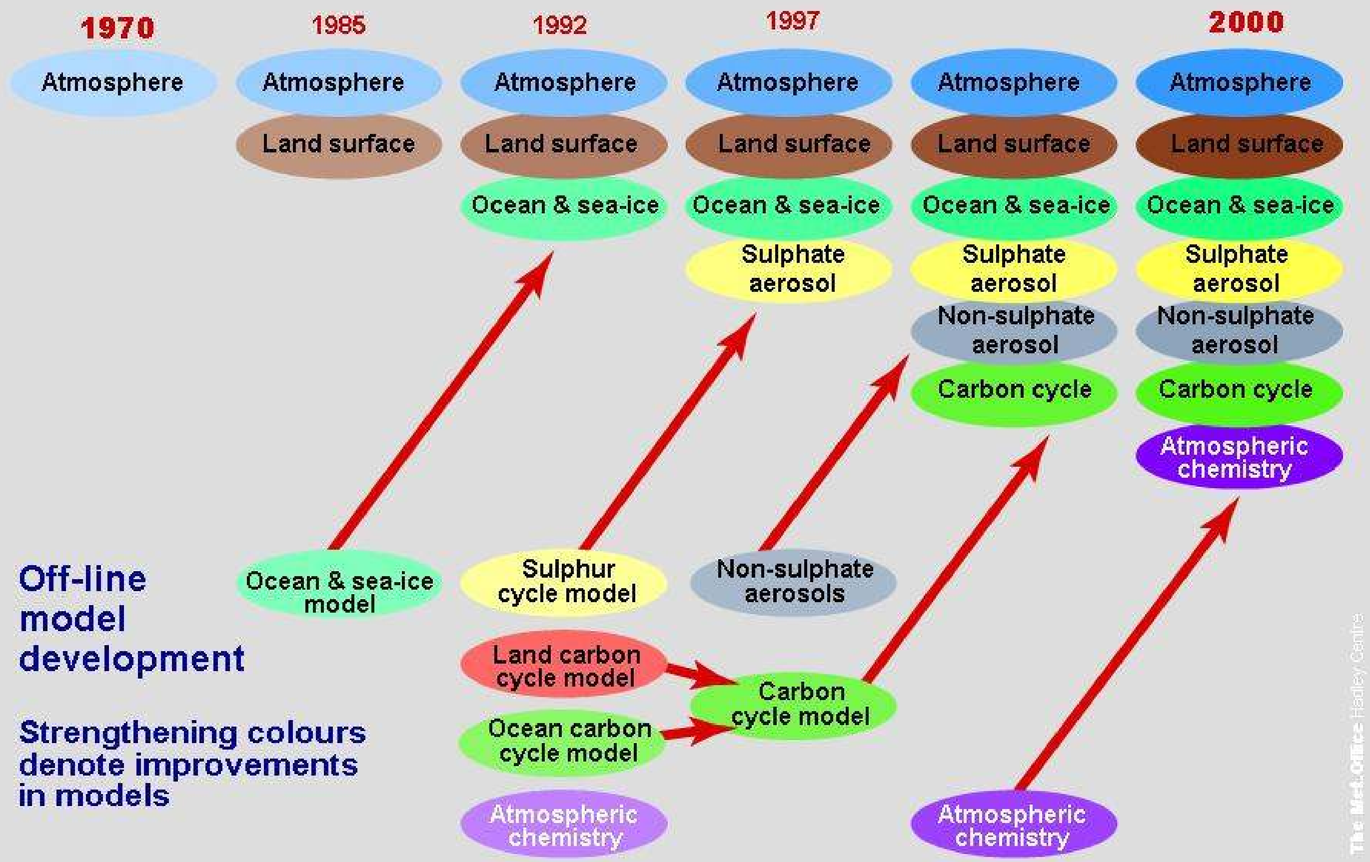
# Weather Models have evolved to to Earth System Models:

What about crops and water?

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# Fundamental issues remain in generic crop/water models..

## Crops

- Impact of extremes (heat, drought stress)
- Crop type representation (e.g. cash crops)
- How/whether irrigation is represented
- Use outside “design region”

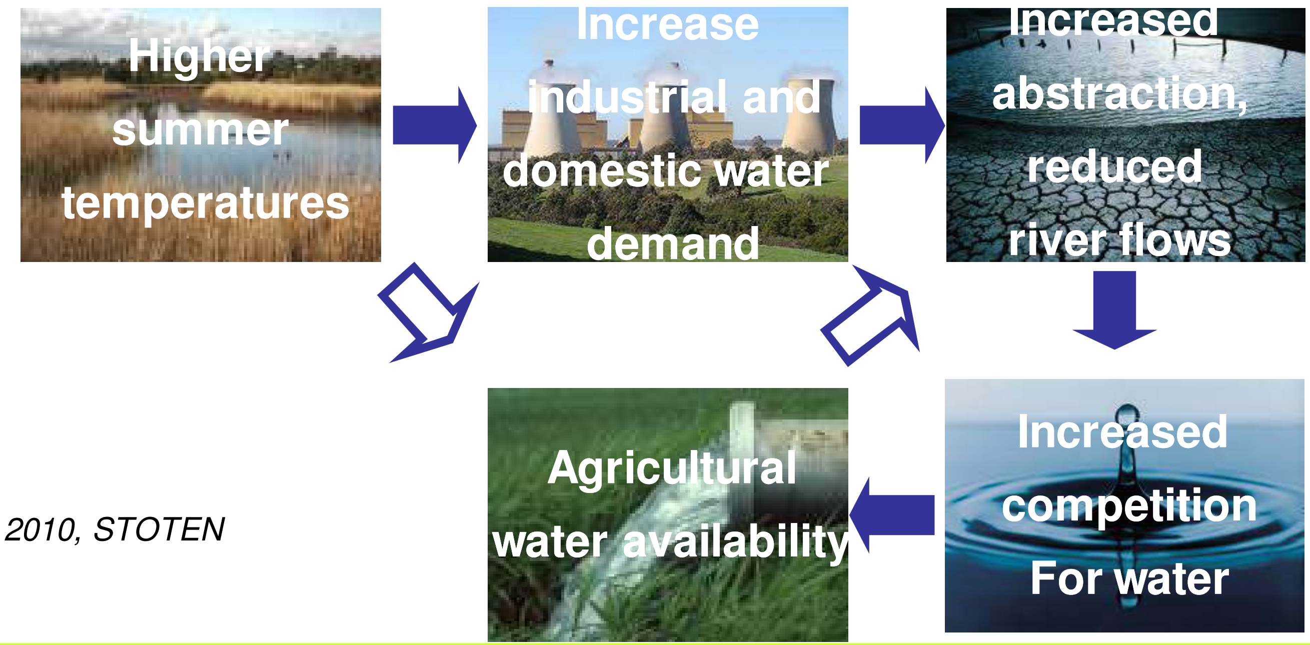
## Water

- Treatment of human influences (dams, abstraction, irrigation)
- Representing agricultural landscapes
- Hydrology: inundation, dry regions

# Interactions between impacts:

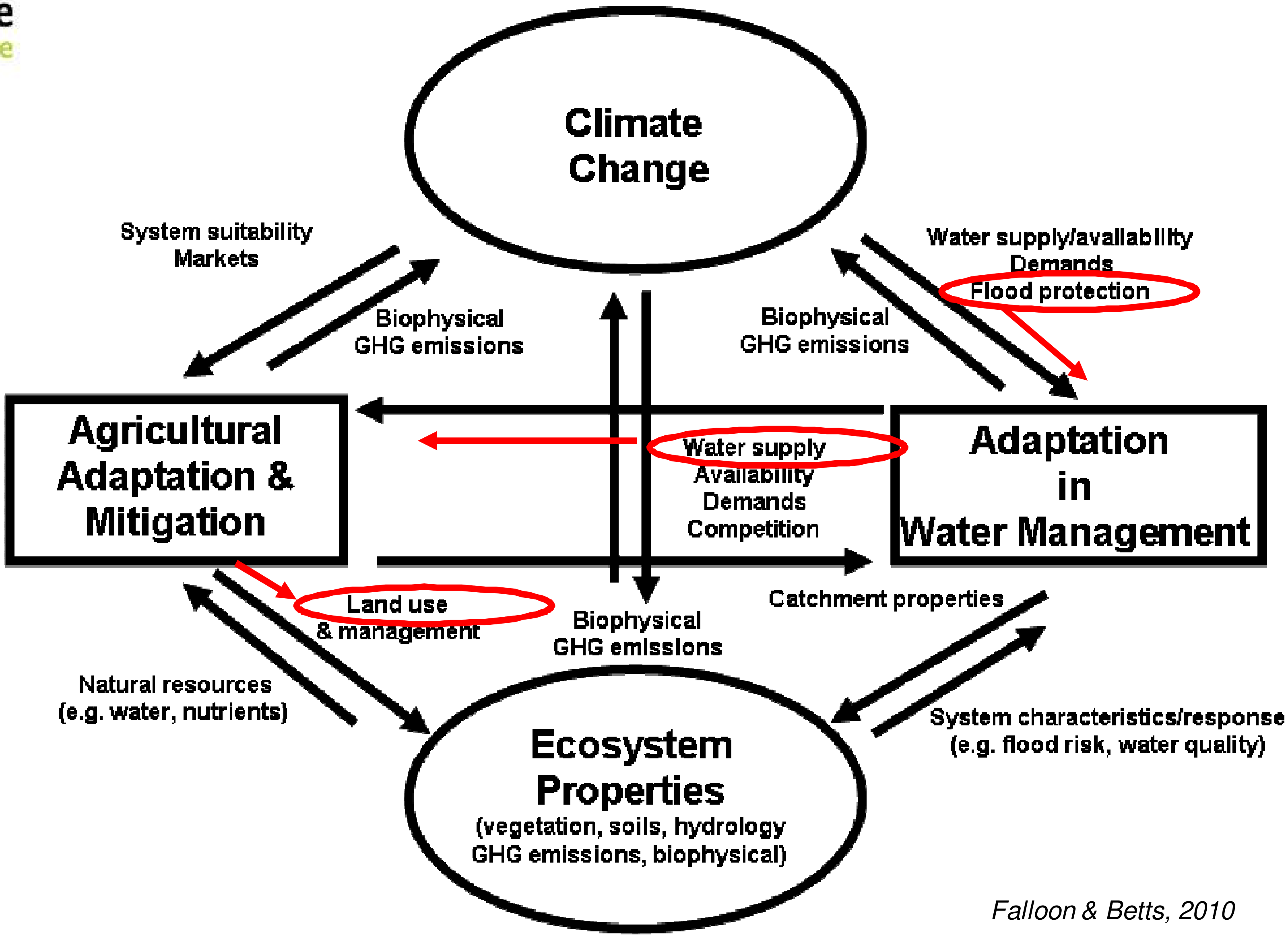
## water and agriculture

- **Water systems** may be affected by climate change, with implications for **agriculture**
  - **Direct**: location, amounts, timing of precipitation, snowmelt, runoff, evaporation, and groundwater recharge
  - **Indirect**: changing water management practices, responses to changing climate




*See also Falloon & Betts, 2010, STOTEN*

# **Complex interactions** between water systems and agriculture in a changing climate




*Falloon & Betts, 2010*

# Improving models & metrics : more relevant agricultural science for policy and business

**Making progress**

- Fast-track impact assessments?
  - "online" impacts
  - Better metrics
- Crop/water model improvement
- Integrated bio-physical assessments

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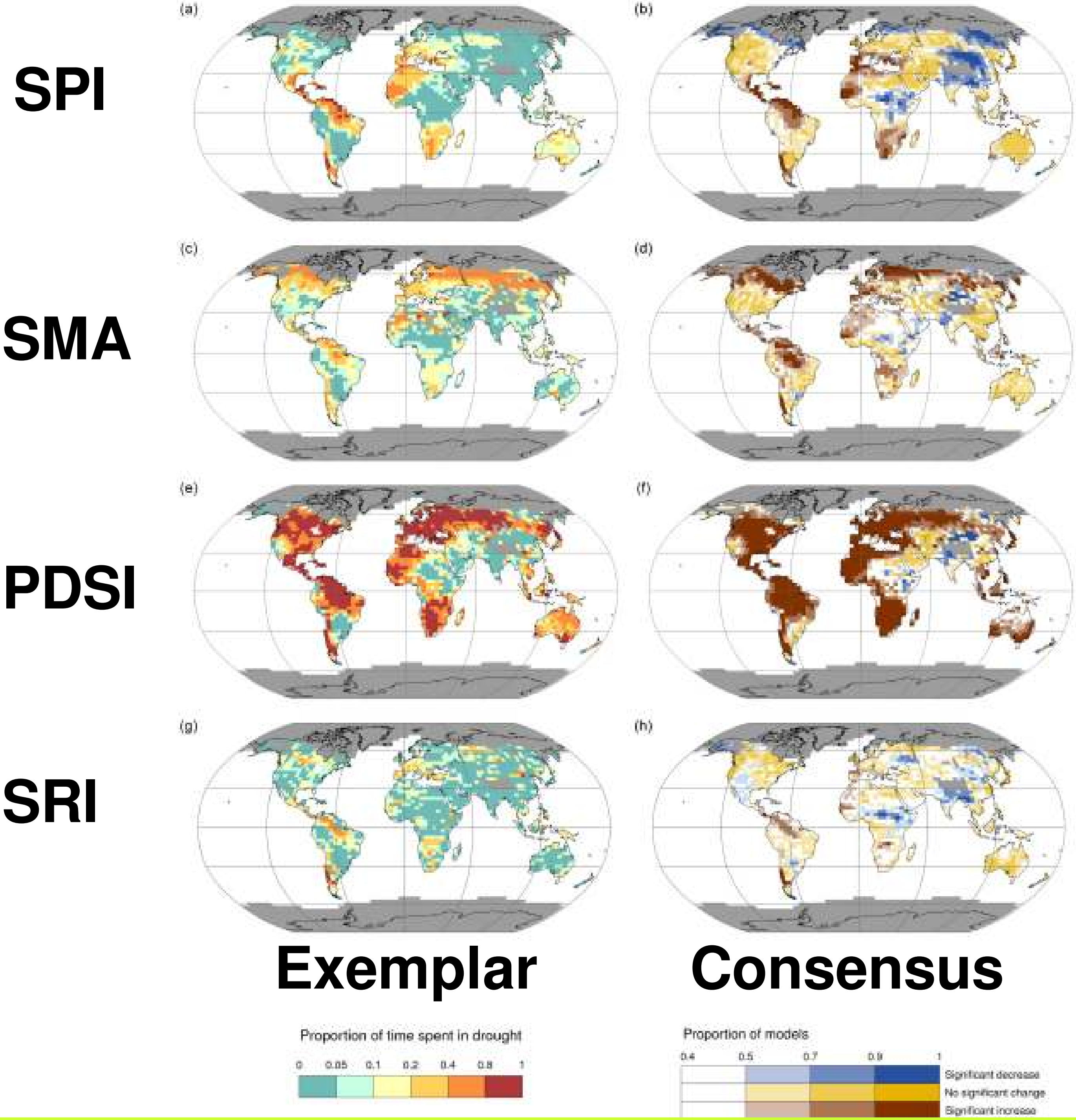
# "Durban" project WP3

Impact calculations for a 57-member earth systems model ensemble (HadCM3C) with two/three scenarios (A1B, RCP2.6, *+RCP8.5*)




# Making standard climate model outputs more relevant to agriculture

Proportion of time in drought, 2080s A1B ($10^{th}$ percentile)

*Taylor et al. 2012*

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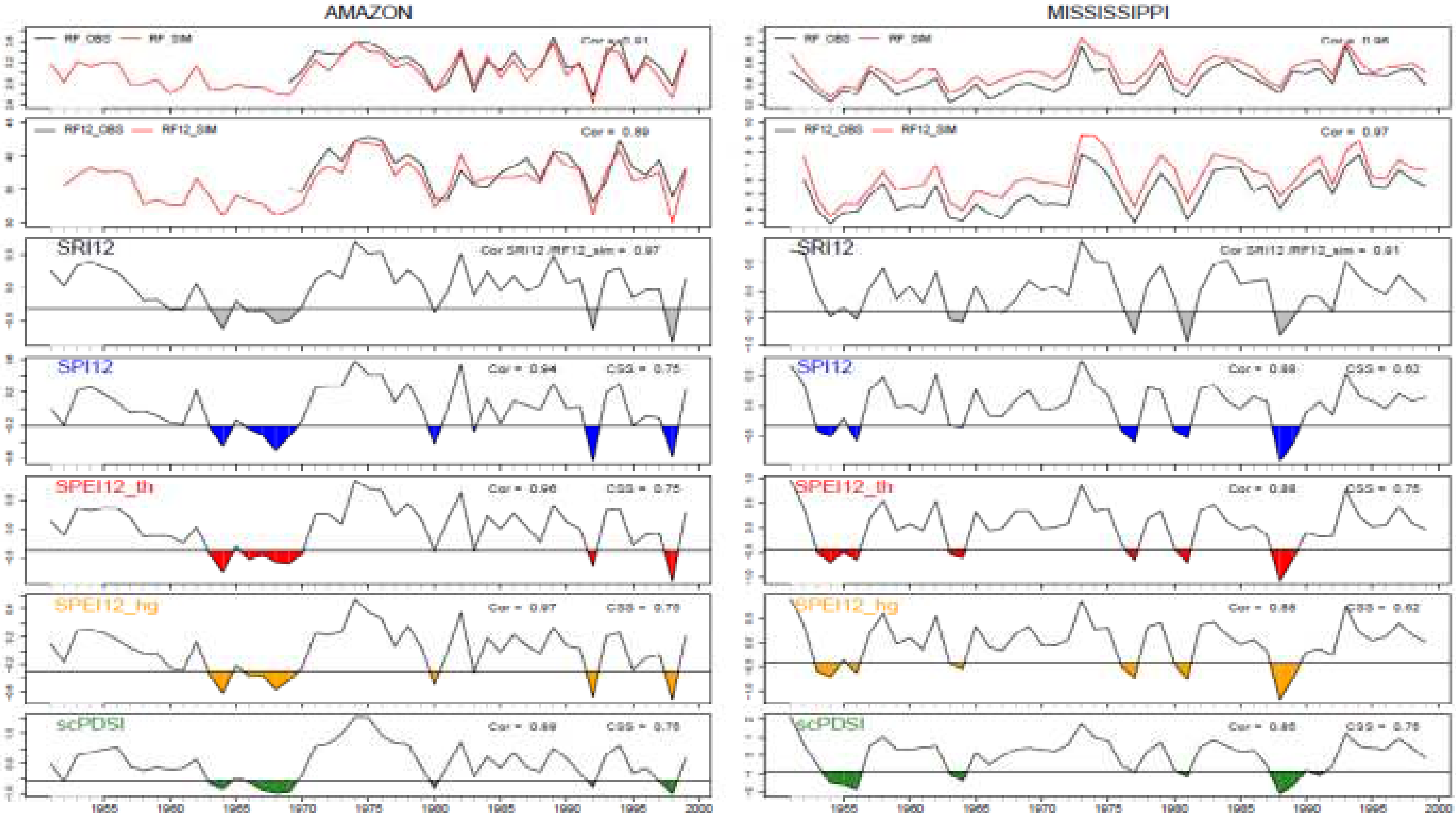
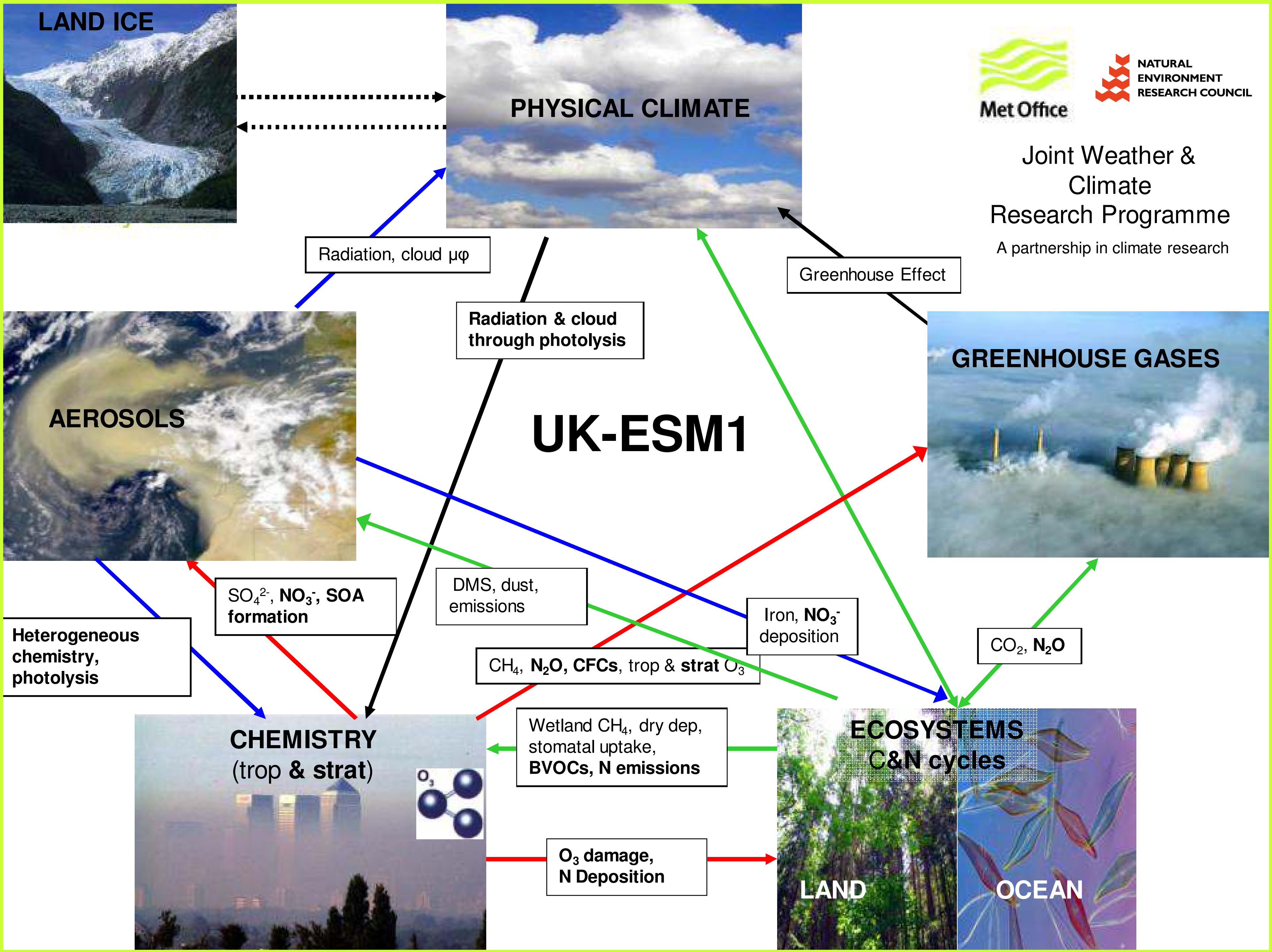
# Benchmarking drought indices against observed river flows

**Similar techniques applied to crop yield/failures to make drought indices more relevant to agriculture?**




*Joetzjer et al. (2013)*


LAND ICE
PHYSICAL CLIMATE
Met Office
NATURAL ENVIRONMENT RESEARCH COUNCIL
Joint Weather & Climate Research Programme
A partnership in climate research
Radiation, cloud μφ
Radiation & cloud through photolysis
Greenhouse Effect
AEROSOLS
UK-ESM1
GREENHOUSE GASES
$SO_4^{2-}$, $NO_3^-$, SOA formation
DMS, dust, emissions
Iron, $NO_3^-$ deposition
Heterogeneous chemistry, photolysis
$CH_4$, $N_2O$, CFCs, trop & strat $O_3$
$CO_2$, $N_2O$
CHEMISTRY (trop & strat)
$O_3$
Wetland $CH_4$, dry dep, stomatal uptake, BVOCs, N emissions
ECOSYSTEMS C&N cycles
$O_3$ damage, N Deposition
LAND
OCEAN

# Developing the integrated land impacts model

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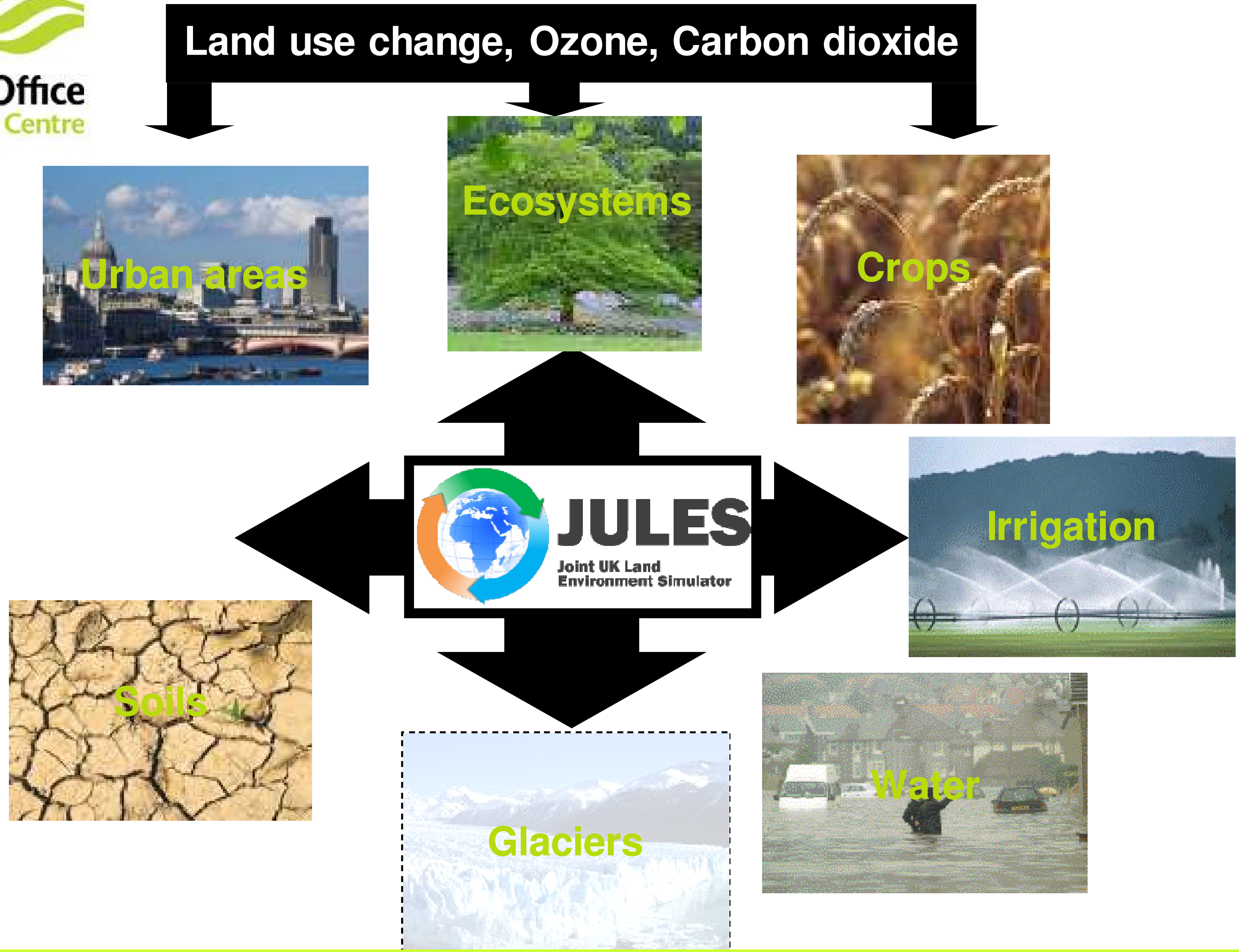
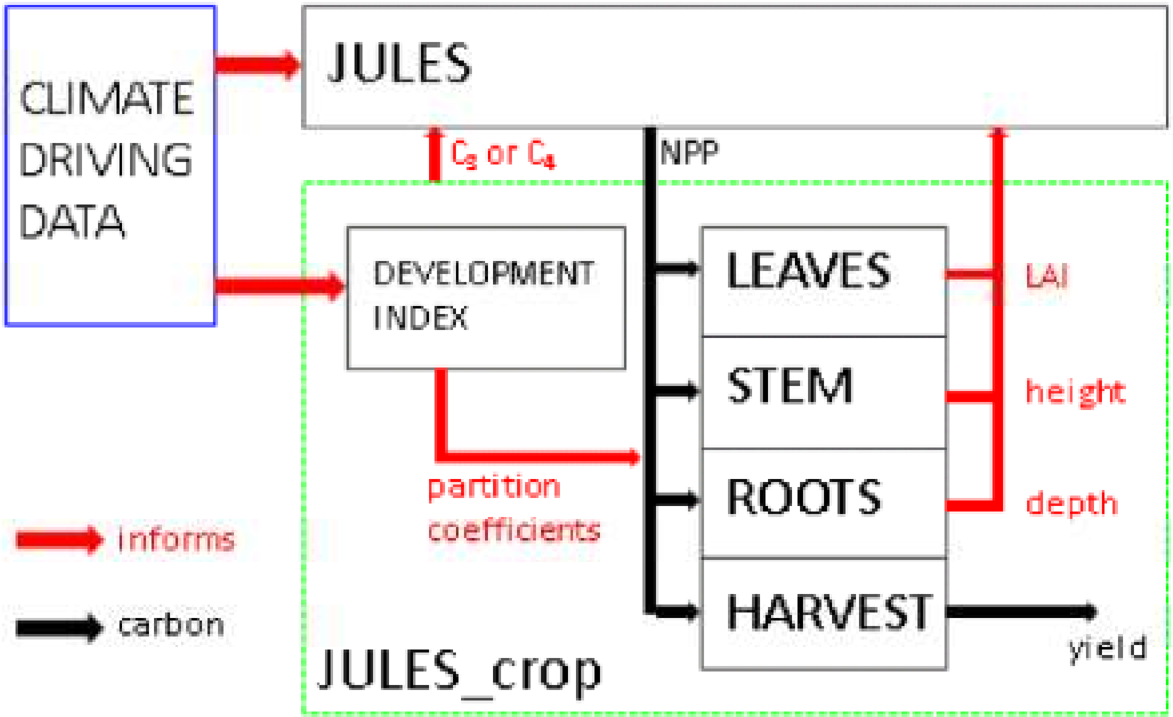


# A generic carbon conserving crop model: **JULES-crop**

- Now in JULES release version.
- Crop Types
  - Wheat, Maize, Soybean, Rice
- Simulates
  - Crop Phenology, Crop yield, Carbon Cycle
- Biogeophysical interaction
  - Albedo, roughness, surface conductance

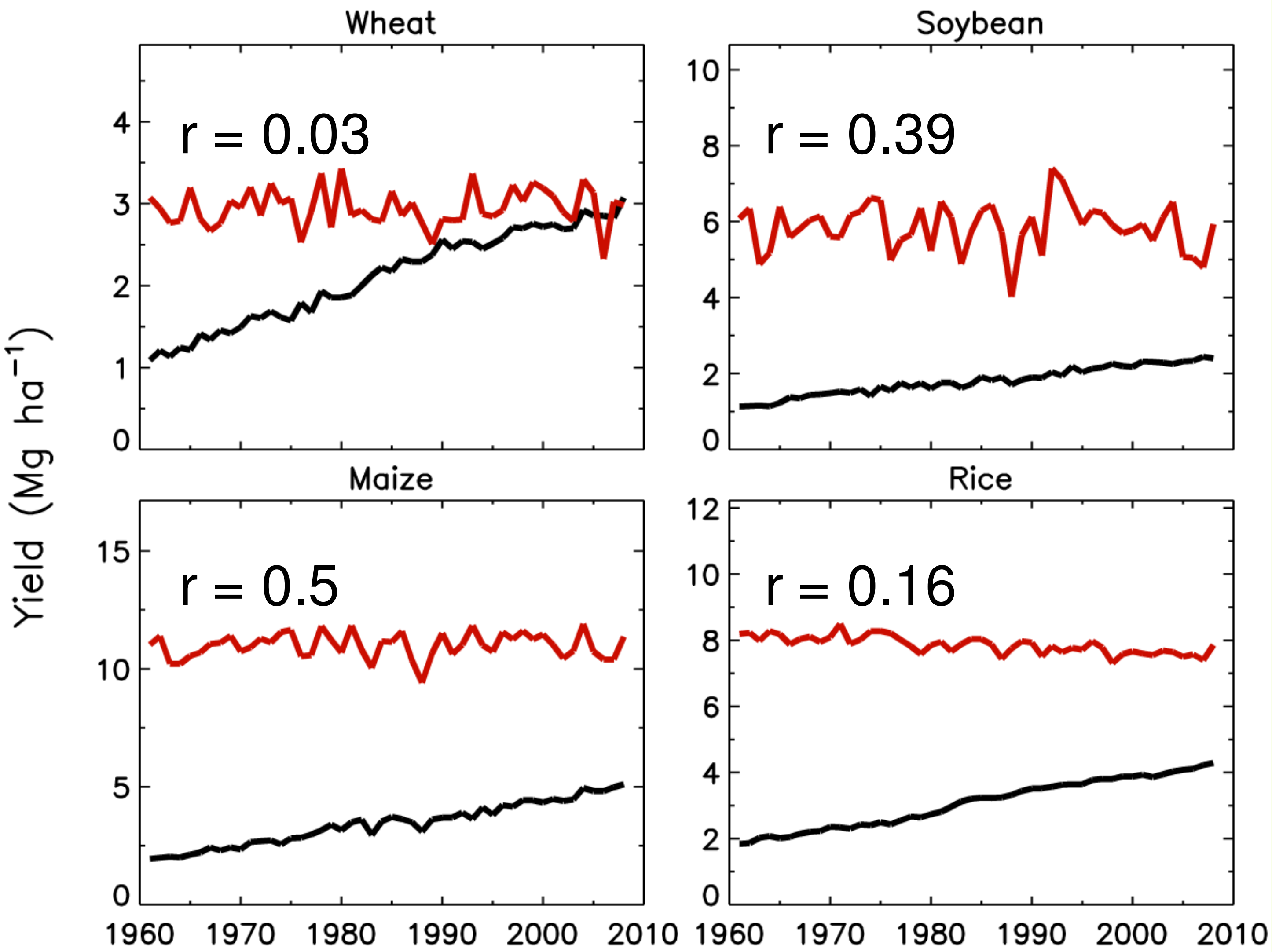



*Osborne et al, 2014, GMD.*

# JULES-crop: global crop yields

## Future?

- Other crops
  - Winter crops
  - "Cash crops"
- High temperature stress
- Drought stress
- Flooding
- Nutients
- Pests/diseases
- Ozone damage

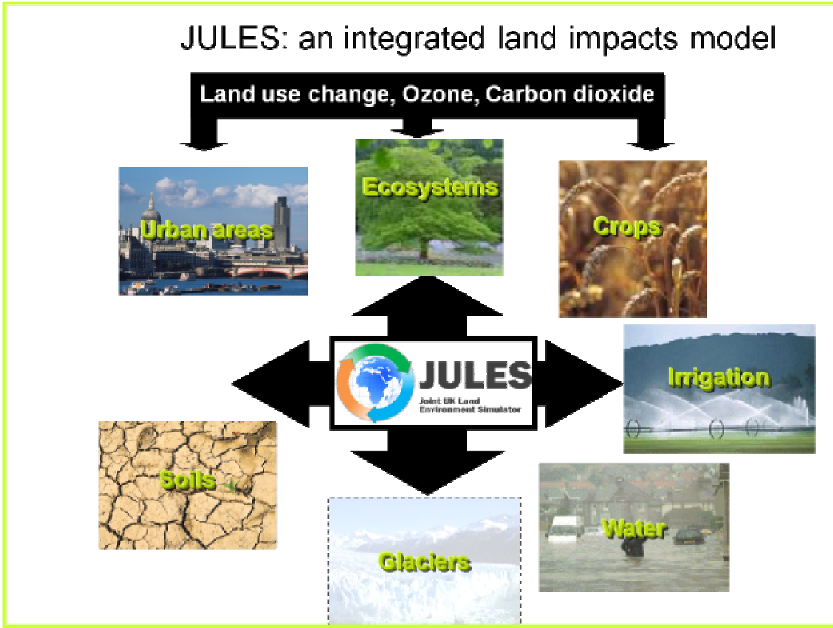



*Osborne et al, 2014, GMD.*

# A framework for integrated regional impact assessments

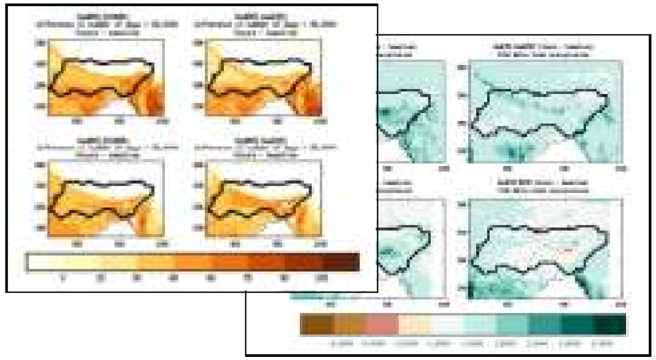
JULES-impacts

model



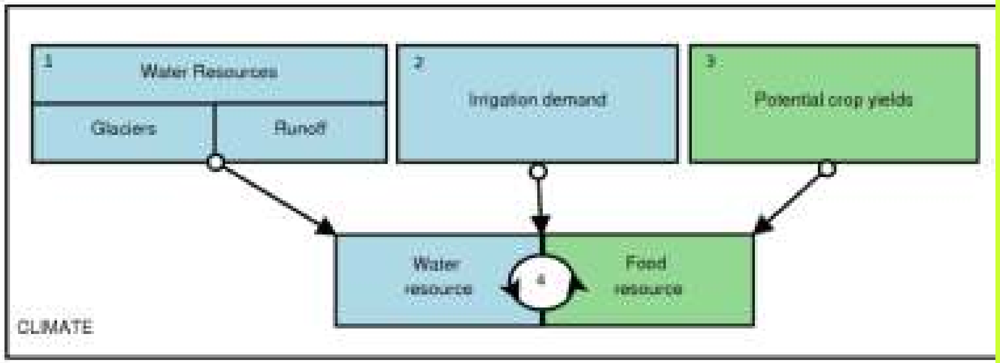

EU HighNoon

Regional climate model simulations



Regional-scale

Integrated assessments



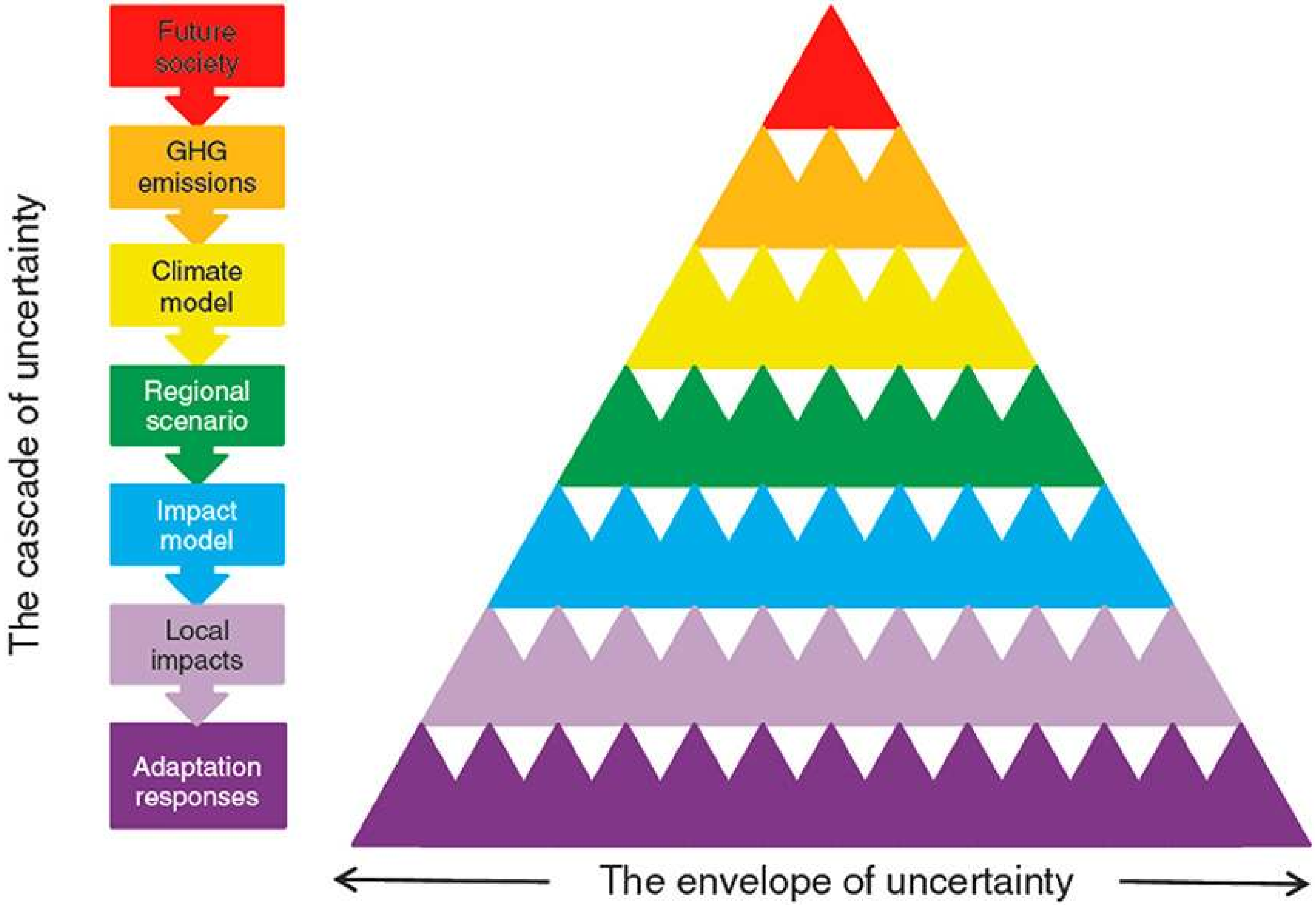

*Mathison et al. 2012,*
*Mathison pers. comm.*

# Better decision making through a robust understanding of impact intercomparison results

**Some of the issues:**

- Large uncertainty ranges in assessments
  - Can we narrow them?
  - Do we understand them?
  - What do they tell us about the models/responses?
  - Can users and policy makers use them?

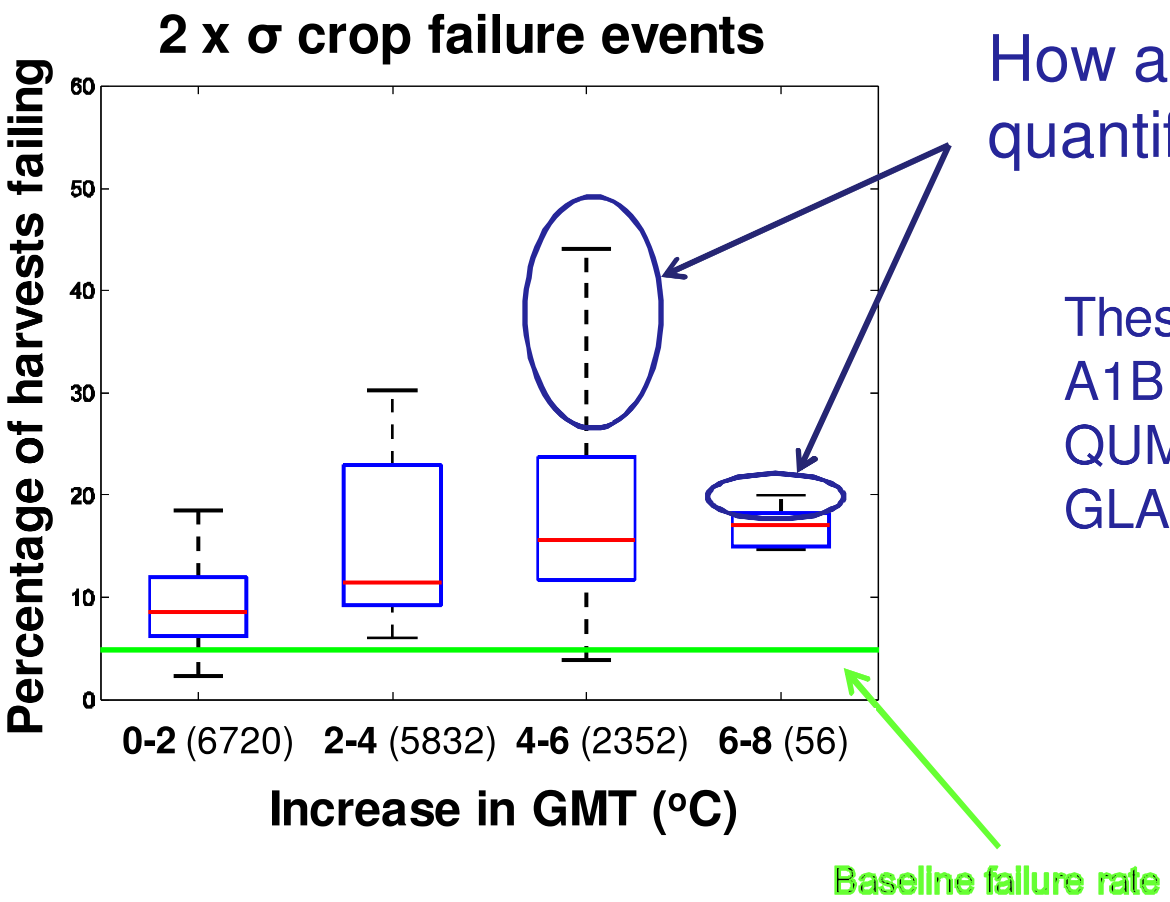
# The cascade of uncertainty




*Wilby & Dessai (2010)*

# How should uncertainty ranges be interpreted?

Error bars or contingency statements?




How accurately can we quantify uncertainty?

These ranges are contingent on:
A1B
QUMP(17)
GLAM(8)

*Challinor et al. (2010)*

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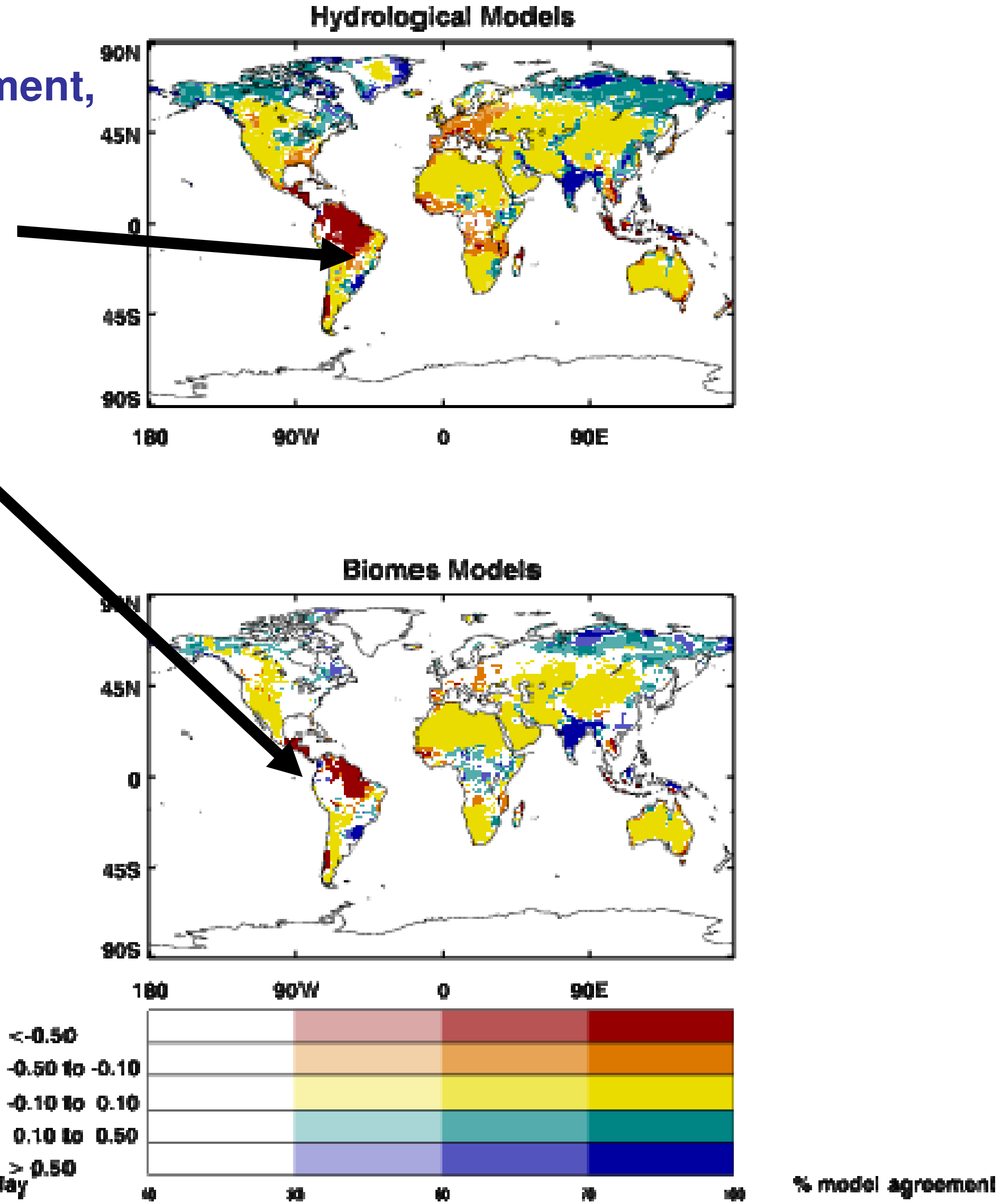
**Less agreement, smaller decreases in ecosystem models**




# Why do different model types give different results?

# Is the experimental design useful?

ISI-MIP models consensus changes in runoff (mm $d^{-1}$) 2080s, RCP8.5

*Davie et al. 2013*

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# What do impact assessments need to tell users?

## Policy maker

•2080s UK food production?
•Global impacts
•Which emissions pathway?

## Industry R&D


•Which crop traits for 2030s?
•Holistic solutions for farmers?

## Farmer

•Which crop next season?
•Land management – days to months?
•Policy compliance?

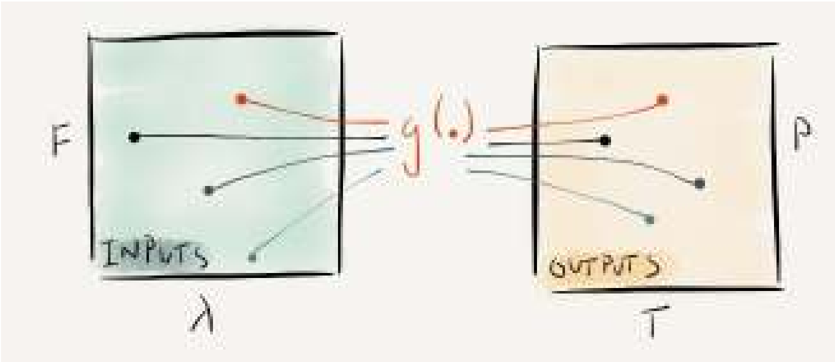
# Better decision making through a robust understanding of impact intercomparison results

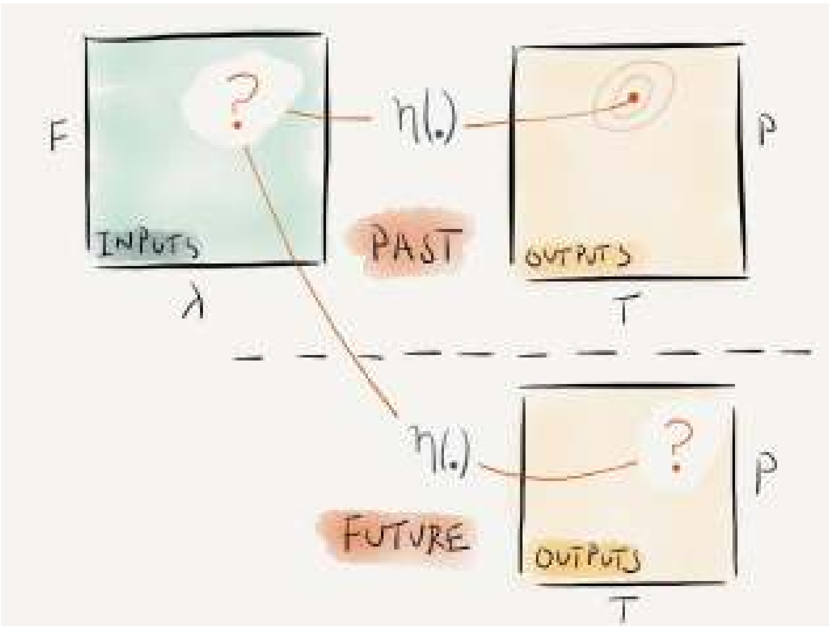
## Making progress

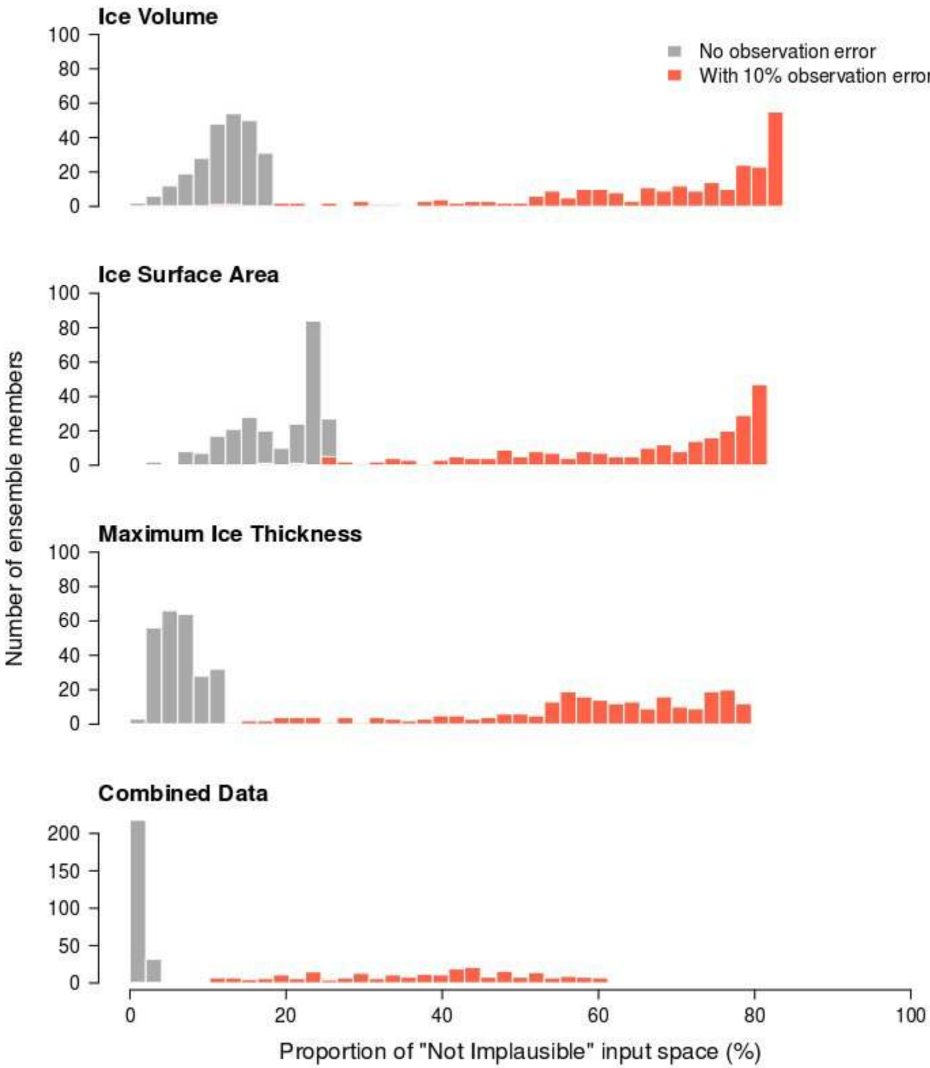
- Making use of statistical techniques and climate methods
- Focused model process-level assessment and development
- Designing ensembles **for** impacts
- Making outcomes more relevant to users
- Top down vs. bottom up approaches

*See also: Challinor et al. (2014); LWEC EQUIP Policy Guidance Note*

# Statistical techniques to understand uncertainties in impacts:




*McNeall et al (2013)*

# Learning from intercomparisons
## (ISI-MIP: Intersectoral Impacts Model Intercomparison Project)

ISI-MIP

Multiple climate models + Multiple global impact models per sector = **Fast track** contribution to AR5

Bias-corrected

**RCP climate projections**
Global: CMIP5

**Socio-economic input**
SSP population and GDP

- Agriculture (AgMIP collaboration)
- Water (WaterMIP collaboration)
- Biomes
- Health
- (coastal infrastructure)

- Synthesis of impacts at different levels of global warming

**ase 2:**

➢ Regional focus

Focus t

➢ Stre

➢ Intermediate goal degree target pre COP21 (2015)

JULES Joint UK Land Environment Simulator

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Centre for Ecology & Hydrology
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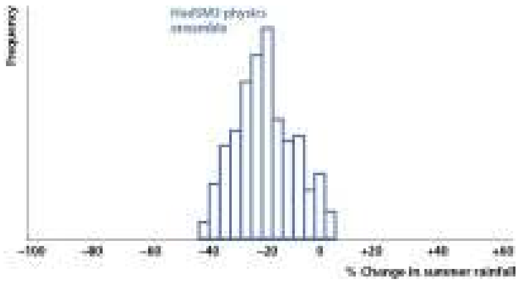
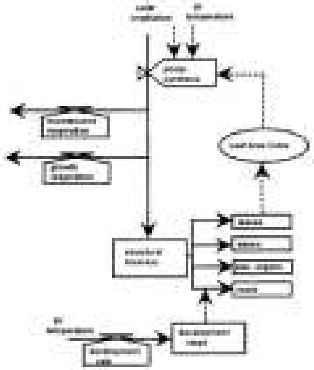
# Ensembles designed for impacts?

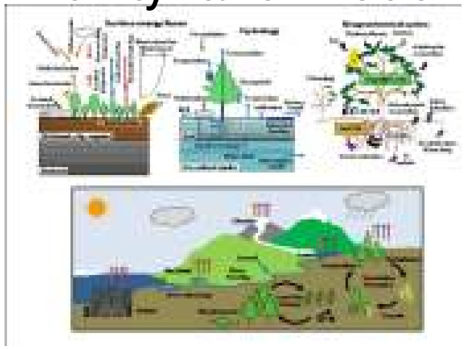
Forest Mortality, Economics, and Climate in Western North America (FMEC)

HadRM3 + TRIFFID ensembles

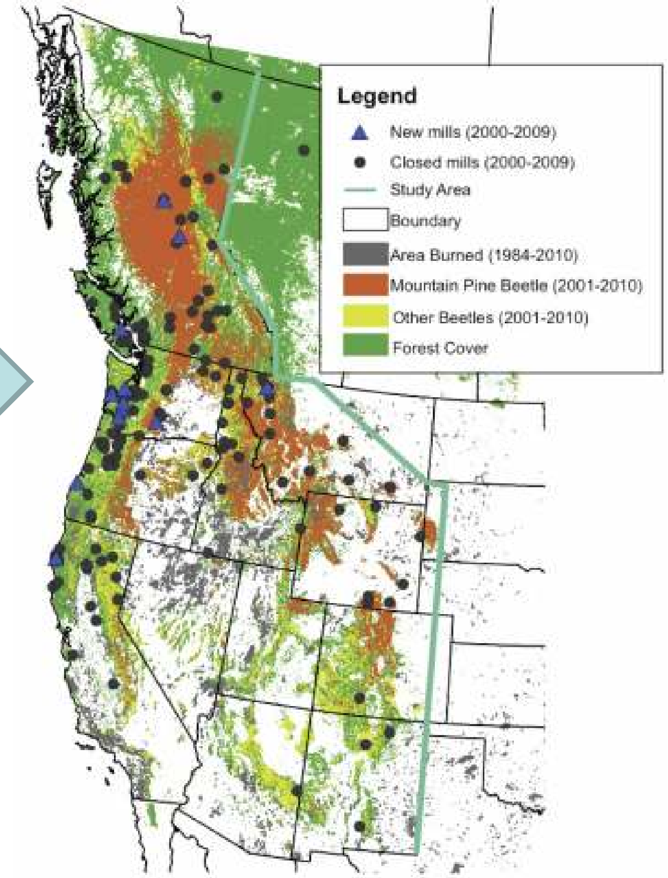




Community land model (CLM)

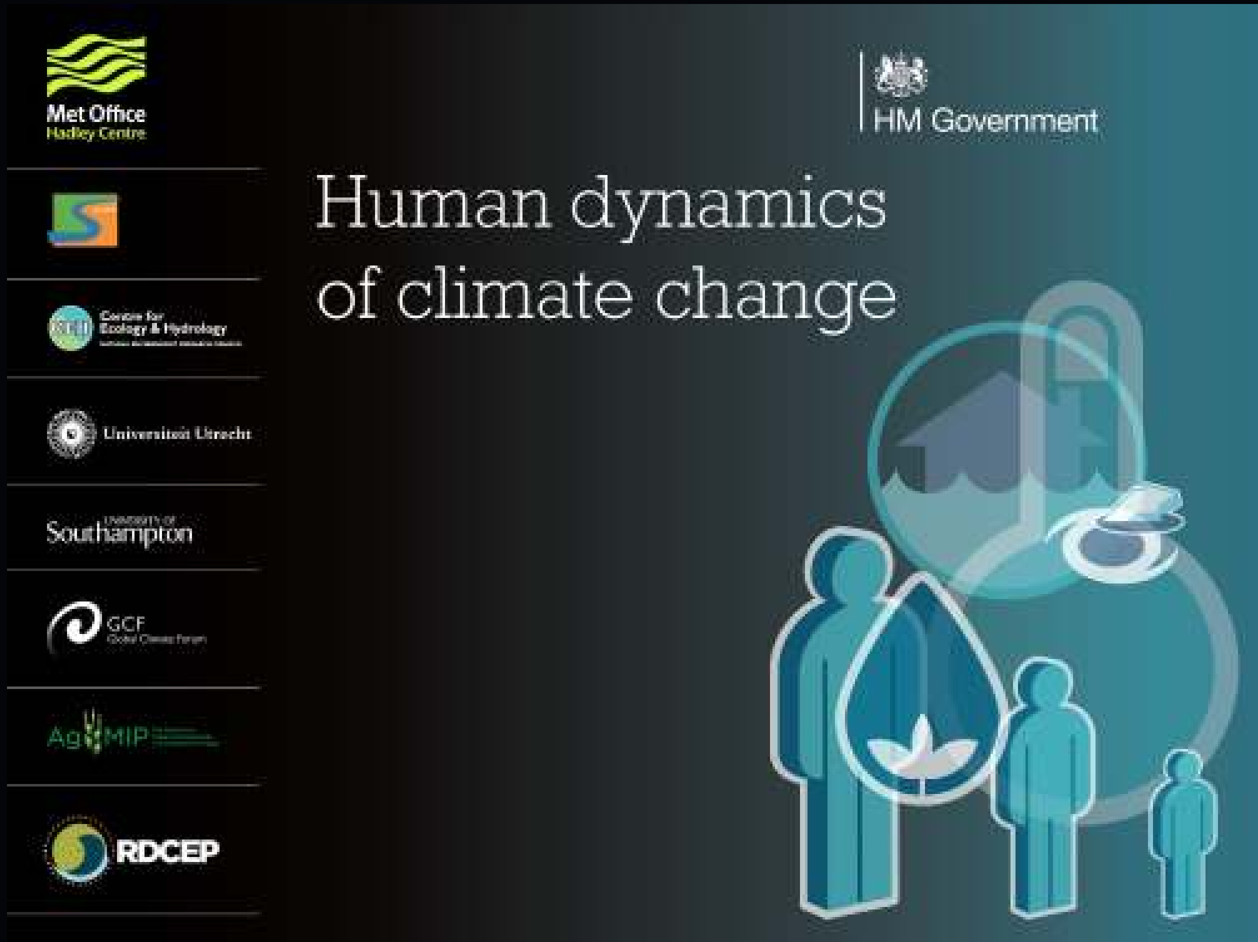


**Impact on forest fire, pests & mortality**



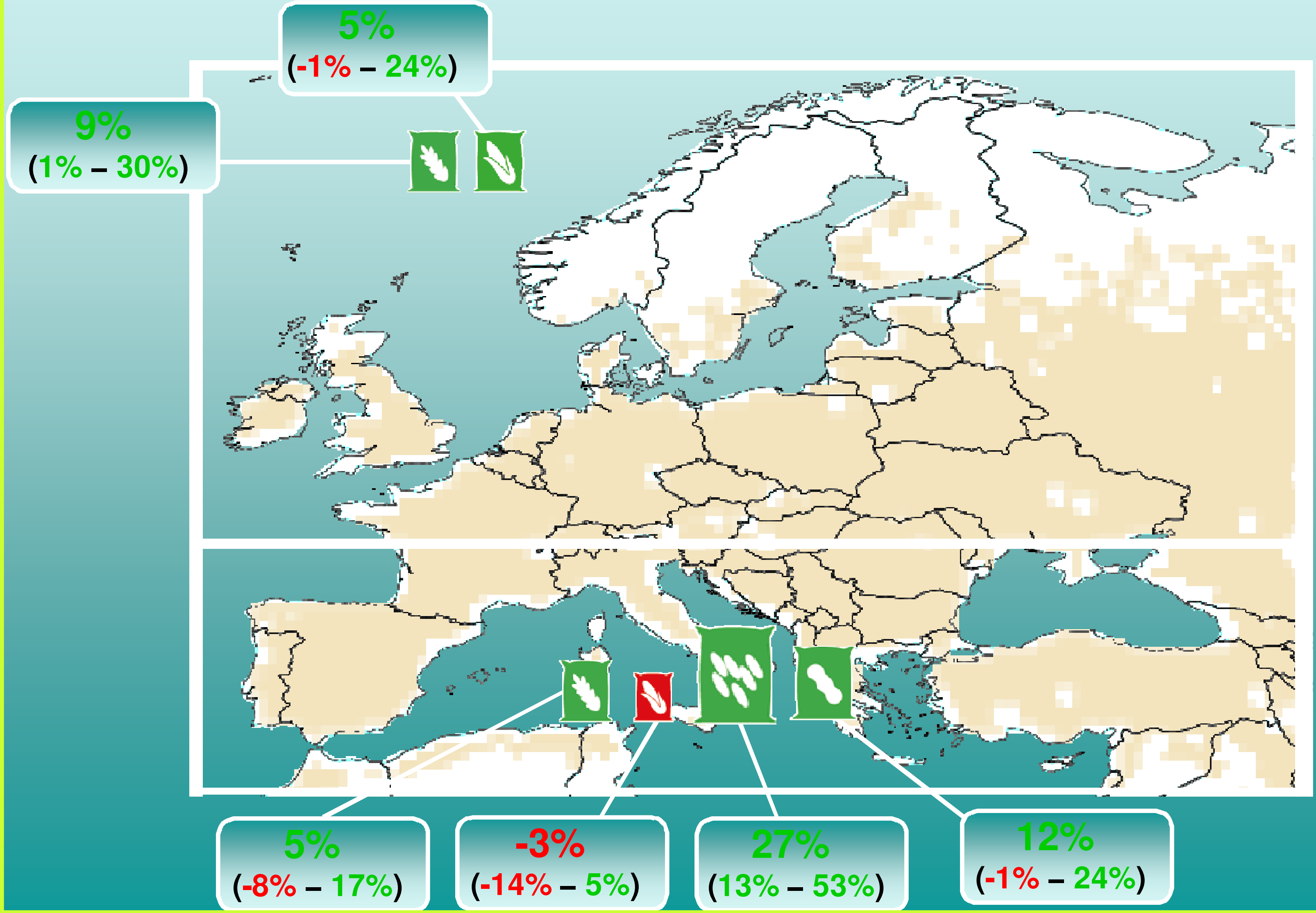
# Presenting impact ensembles to decision-makers

- Latest climate projections
- ‘Business-as-usual’ greenhouse gas concentration scenario (RCP 8.5)
- ‘Middle of the road’ population scenario (SSP2)
- Changes from present day to end of century

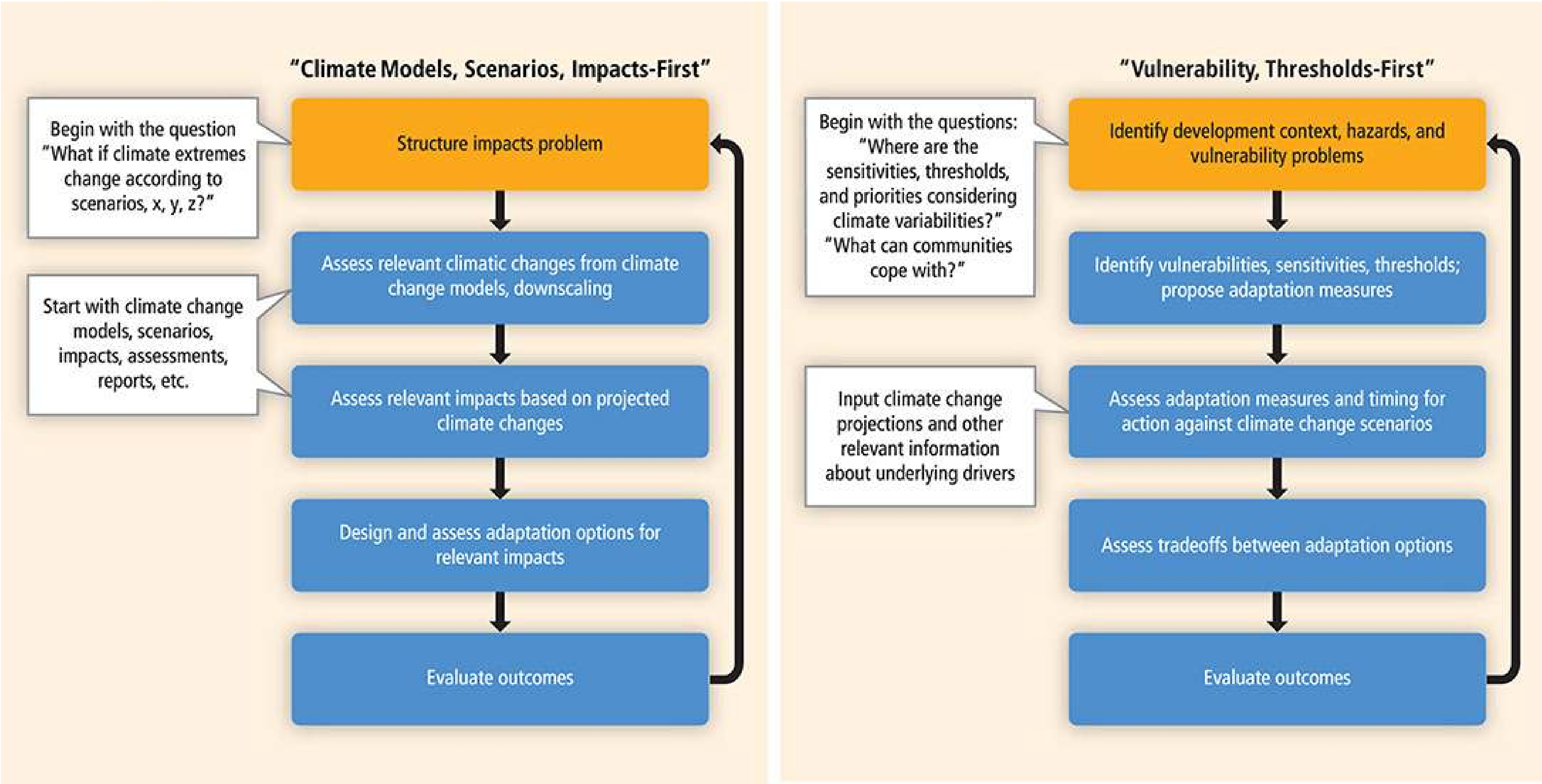


# Europe crop yield changes:

## Gains in the North; some losses in the South

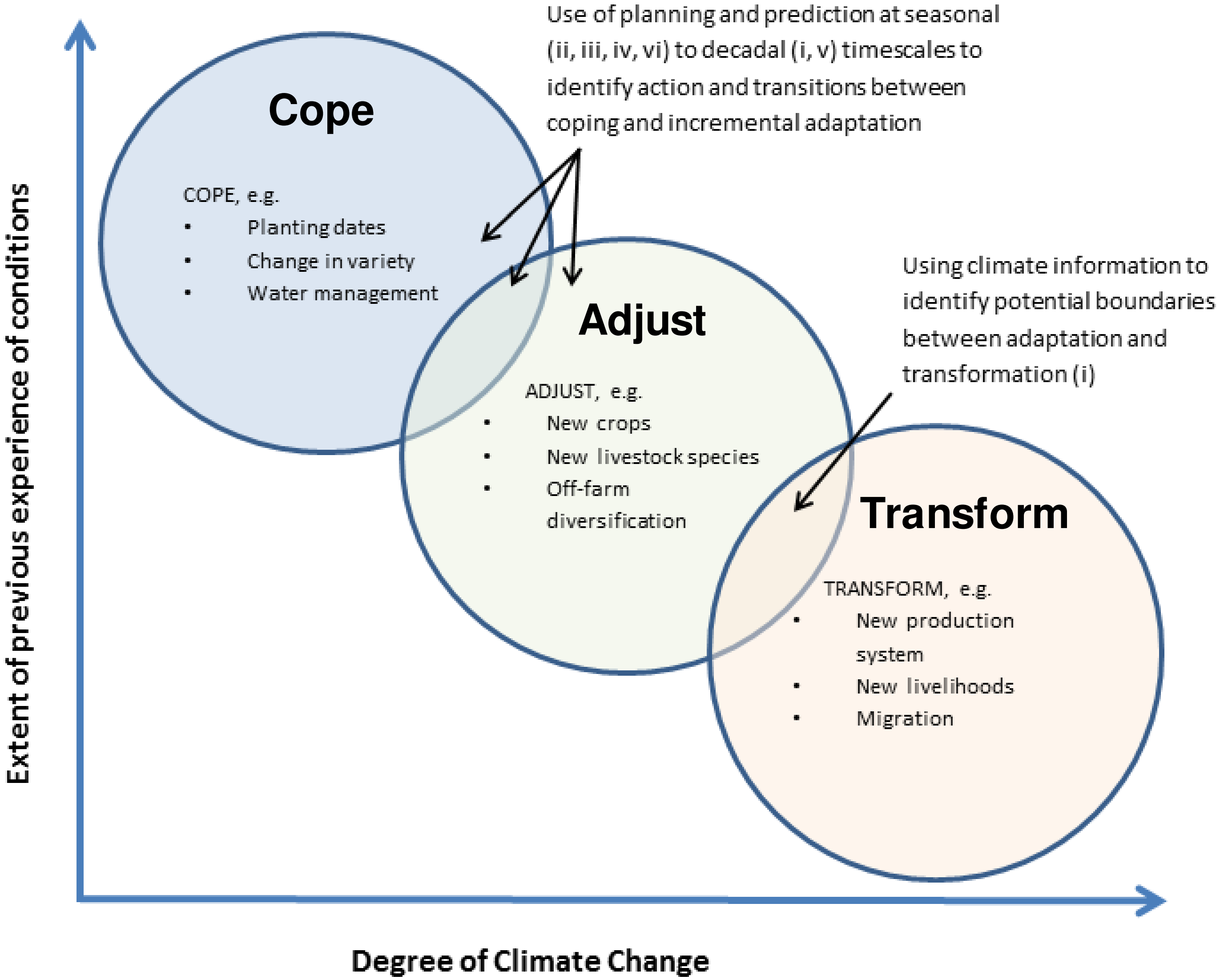


# Top down vs. bottom up approaches



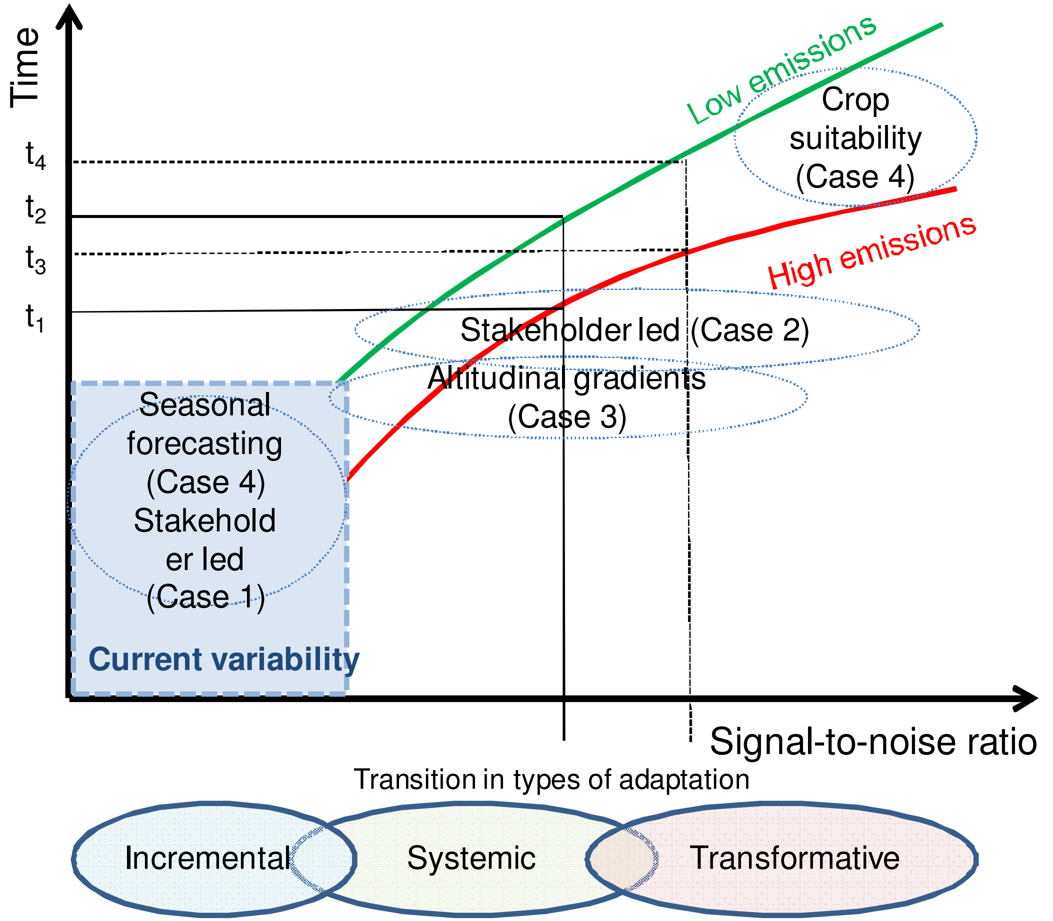

*IPCC SREX (2012)*

# Types of adaptation



# When are transitions in adaptation required?

## Answers from top-down and bottom-up analyses




**Bottom-up approaches particularly important**

**Top-down approaches particularly important**

*Vermuelen et al. (2013) - PNAS*

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# Applying seasonal forecasts to provide usable climate services for agriculture and water

# Future changes in UK climate

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- Headline message from UKCP09:
  - Hotter drier summers
  - Warmer wetter winters
- *But* in the recent past..
  - Cold winter 2010
  - Wet summer 2011
  - Cold spring 2013

…Headline is for average changes

What can we say about seasonal climate *extremes*?

Belfast, Northern Ireland, - 23rd October 2011

By 2100:

Very hot summers increase 20-fold

Very wet winters increase six-fold

Very dry summers increase eight-fold

But:

35% chance of wet summer until 2040s

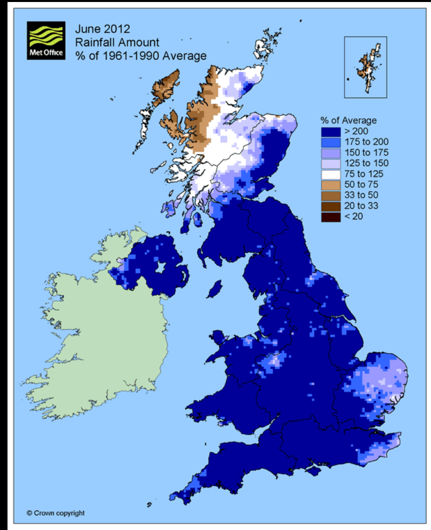
20-30% chance of cold winters until 2020s

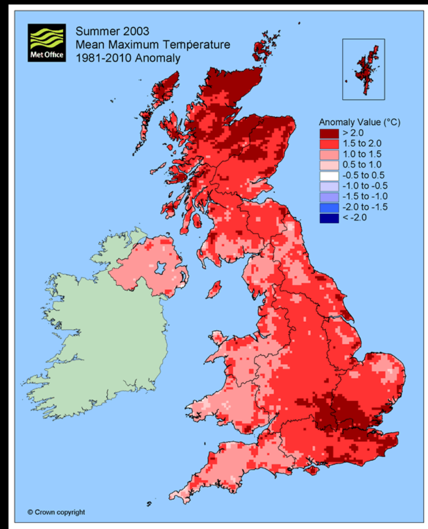
*Sexton & Harris (2014) submitted*

# Unusual seasons and variability are important,

## not just long-term averages

- Summer 2012, UK
  - Wettest summer since 1912
  - Wheat yields down 15%
  - Cost insurers £800 million
- Summer 2003, Europe
  - Hottest summer in Europe since 1540
  - River Danube:
    - Worst drought for over 50 years
    - Levels dropped by 50cm
    - Reduced electricity production in Romania.
  - Very likely that human influence at least doubled risk of temperatures
  - Normal by 2040s and cool by 2080s



# Can we be better prepared for extreme seasons?

## Improved skill in Monthly to Seasonal Forecasts for UK winters

**Recent cold snap: March 2013**

DfT notified on 4th January:

*"…there is now an increasing risk of cold conditions returning later in January and an increased chance of wintry conditions starting later this month…"*

"Wintry weather brings disruption to airports, road and rail networks across the UK, with more snow and ice on the way"

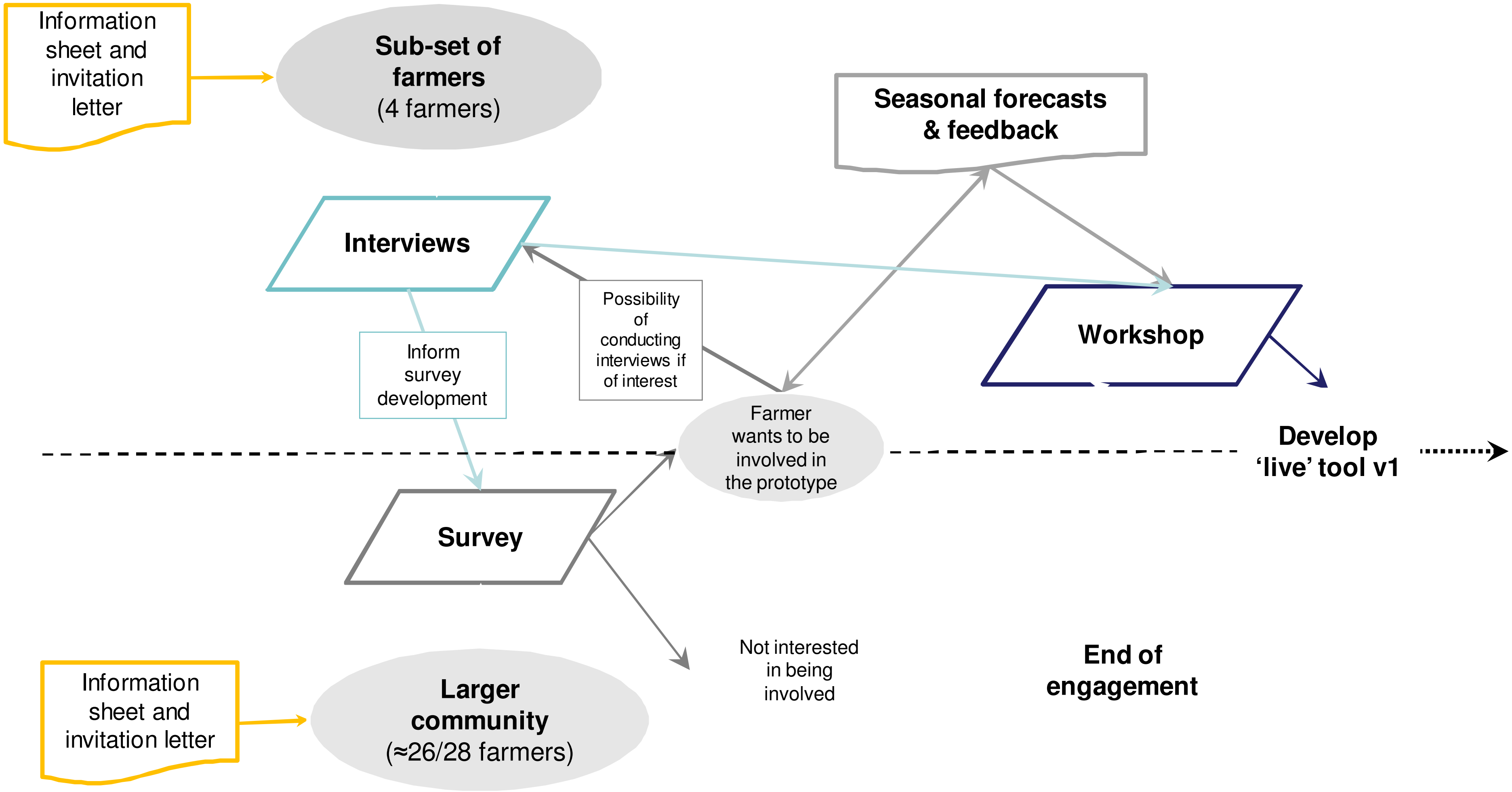
The Guardian 20th Jan

**Working with stakeholders to develop prototypes** e.g.: UK land management tool (cover crops) with Clinton Devon Estates

# EUPORIAS land management prototype

Farmers' engagement, activities, and information pathways

*(Marta Soares, U Leeds)*



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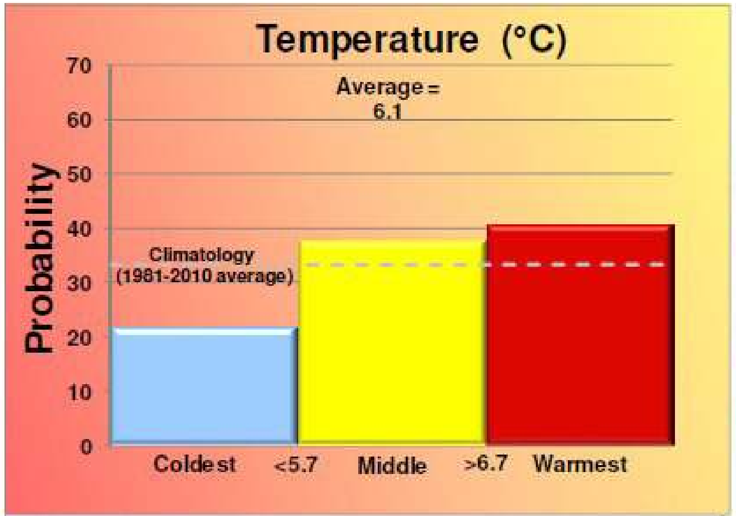
# Devon outlook for November 2014-January 2015

issued end October 2014

***The latest predictions for November-December-January favour <u>above-average</u> Devon-mean temperature and precipitation.***

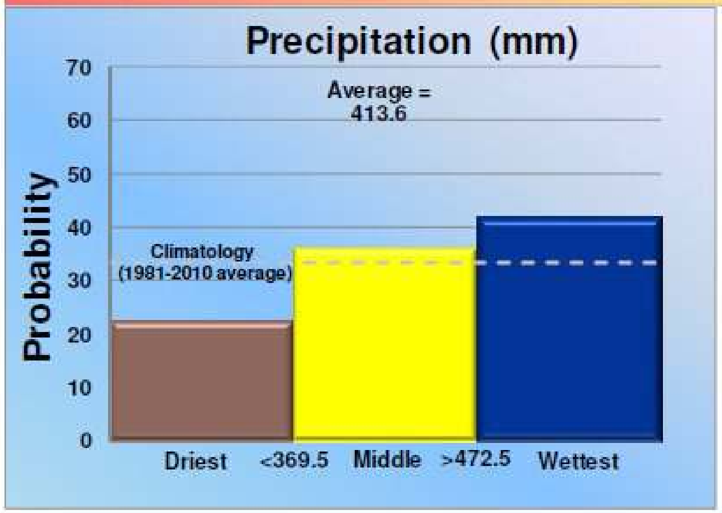



**Temperature**

The probability that the Devon-mean temperature for November-December–January will fall into the *warmest* of our three categories is around 22%

The probability of temperature falling into the *coldest* of our three categories is close to 41%

(the 1981-2010 probability for each of these categories is 33%).




**Precipitation**

The probability that the Devon-mean precipitation for November-December–January will fall into the *wettest* of our three categories is around 23%

The probability of precipitation falling into the *driest* of our three categories is close to 42%

(the 1981-2010 probability for each of these categories is 33%).

The bar charts show the <u>probability</u> that Devon-average temperature (top) or precipitation (bottom) for the three month period will fall into three different categories (coldest or driest 33%, near average, and wettest or warmest 33%). The dashed lines show the <u>probability</u> based on long-term observational records (between 1981-2010). The numbers on the chart show the actual temperature and precipitation values (for the coldest/driest 33%, average, and warmest/wettest 33%) from long-term observational records (between 1981-2010).

**See overleaf for full details on how to interpret this forecast.**

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# High-resolution models for assessing impacts of climate extremes at catchment scale

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# Rainfall in 1.5km vs. 12km model

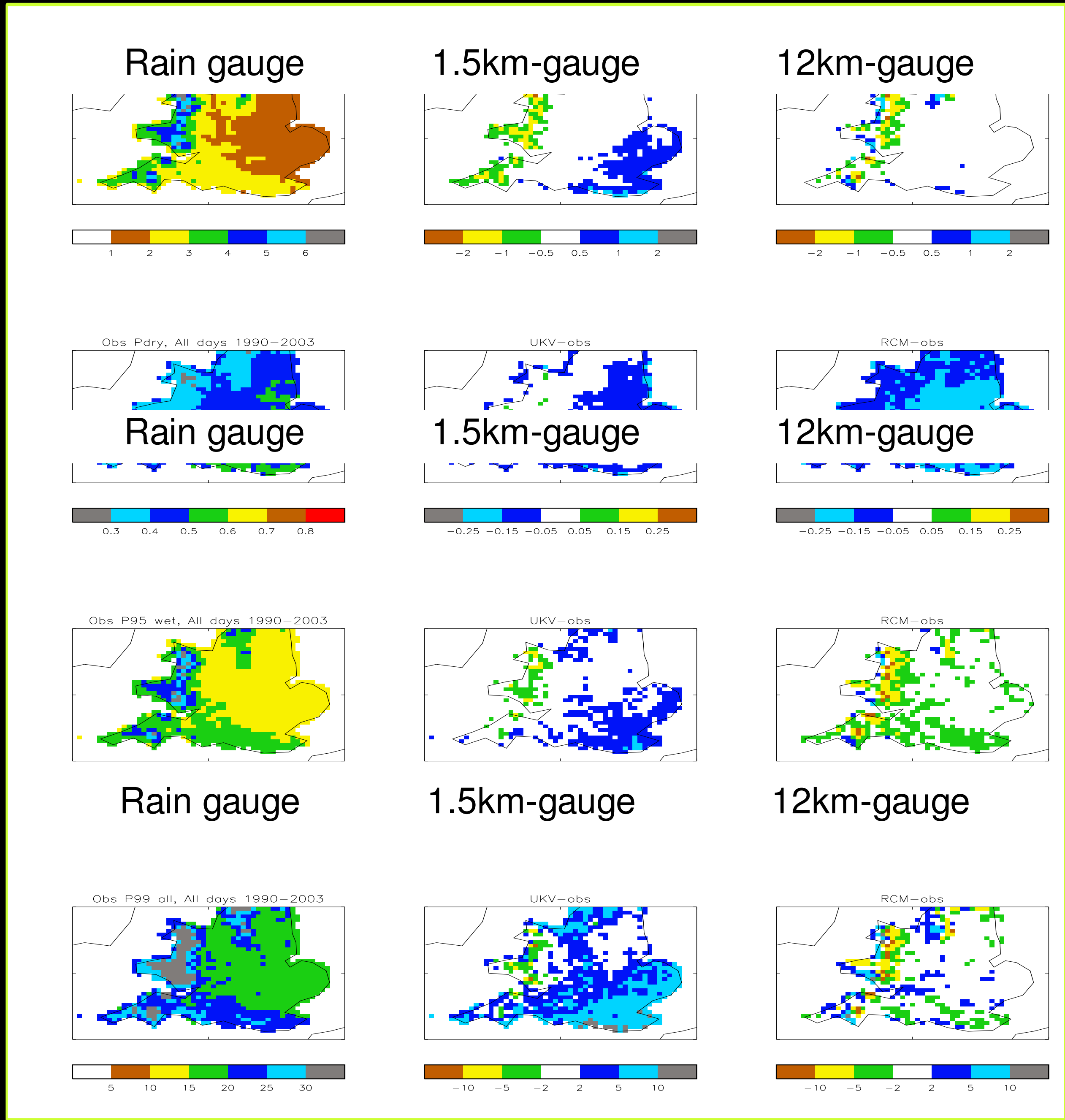
(1989-2008)

Obs | Bias | Bias

Mean precip

Dry day occurrence

Heavy precip



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# Better rainfall extremes, different future changes in high-resolution models

## Future change in heavy hourly rainfall (upper 5%)

Current Capability: 12km model

Future Capability: 1.5 km model

NERC SCIENCE OF THE ENVIRONMENT

Changing water cycle

WINTER

NERC project NUTCAT-2050

What do these changes mean for nutrient transfers in small UK catchments?

SUMMER


−5.0 −2.0 −1.0 −0.5 0.5 1.0 2.0 5.0 mm/hour

*Kendon et al. 2014*

# Simulating heavy rainfall events: Nested Unified Model Suite

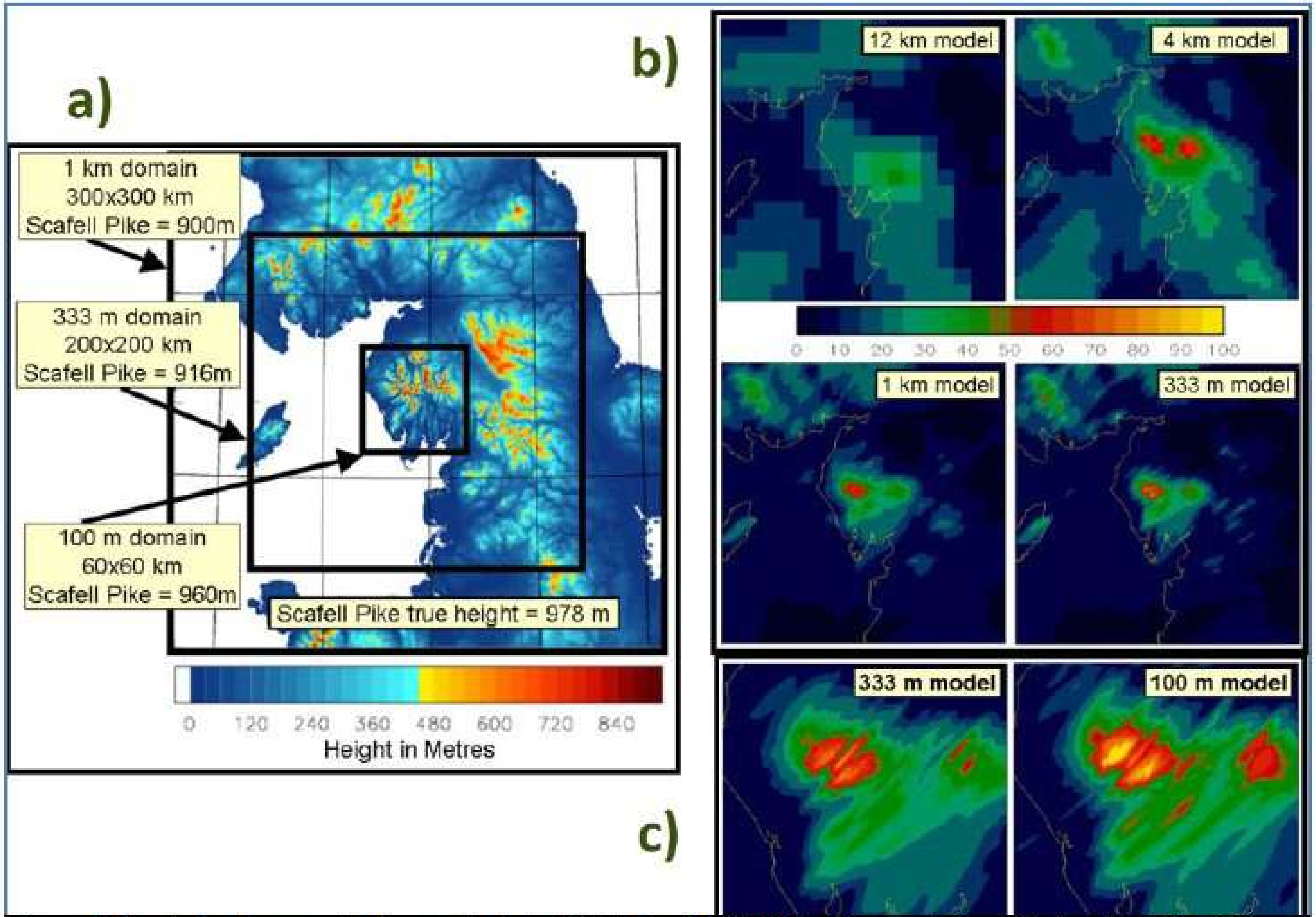
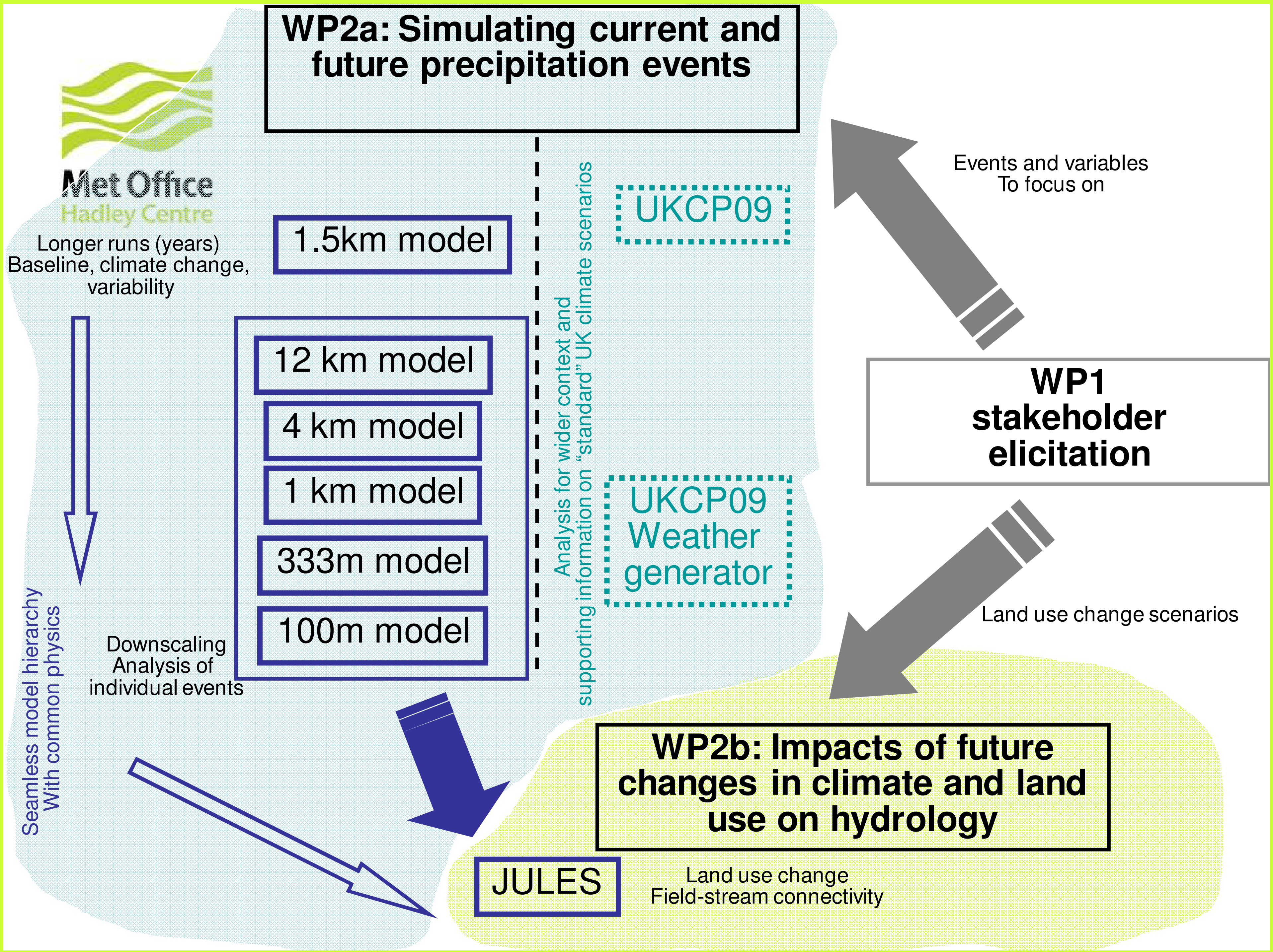



Figure 4: Simulating heavy rainfall over the Lake District on 24/09/2011: a The nested model domains (1km, 333m and 100m resolution) and orography; b) 22 hour rainfall totals over the 333m model domain; c) 21 hour rainfall totals over the 100m model domain (Webster, 2010)



WP2a: Simulating current and future precipitation events
Met Office
Hadley Centre
Longer runs (years)
Baseline, climate change, variability
1.5km model
12 km model
4 km model
1 km model
333m model
100m model
Downscaling
Analysis of individual events
Seamless model hierarchy
With common physics
Analysis for wider context and supporting information on "standard" UK climate scenarios
UKCP09
UKCP09 Weather generator
Events and variables
To focus on
WP1 stakeholder elicitation
Land use change scenarios
WP2b: Impacts of future changes in climate and land use on hydrology
JULES
Land use change
Field-stream connectivity

# Estimating nutrients in catchments to 2050

## (NERC NUTCAT-2050)

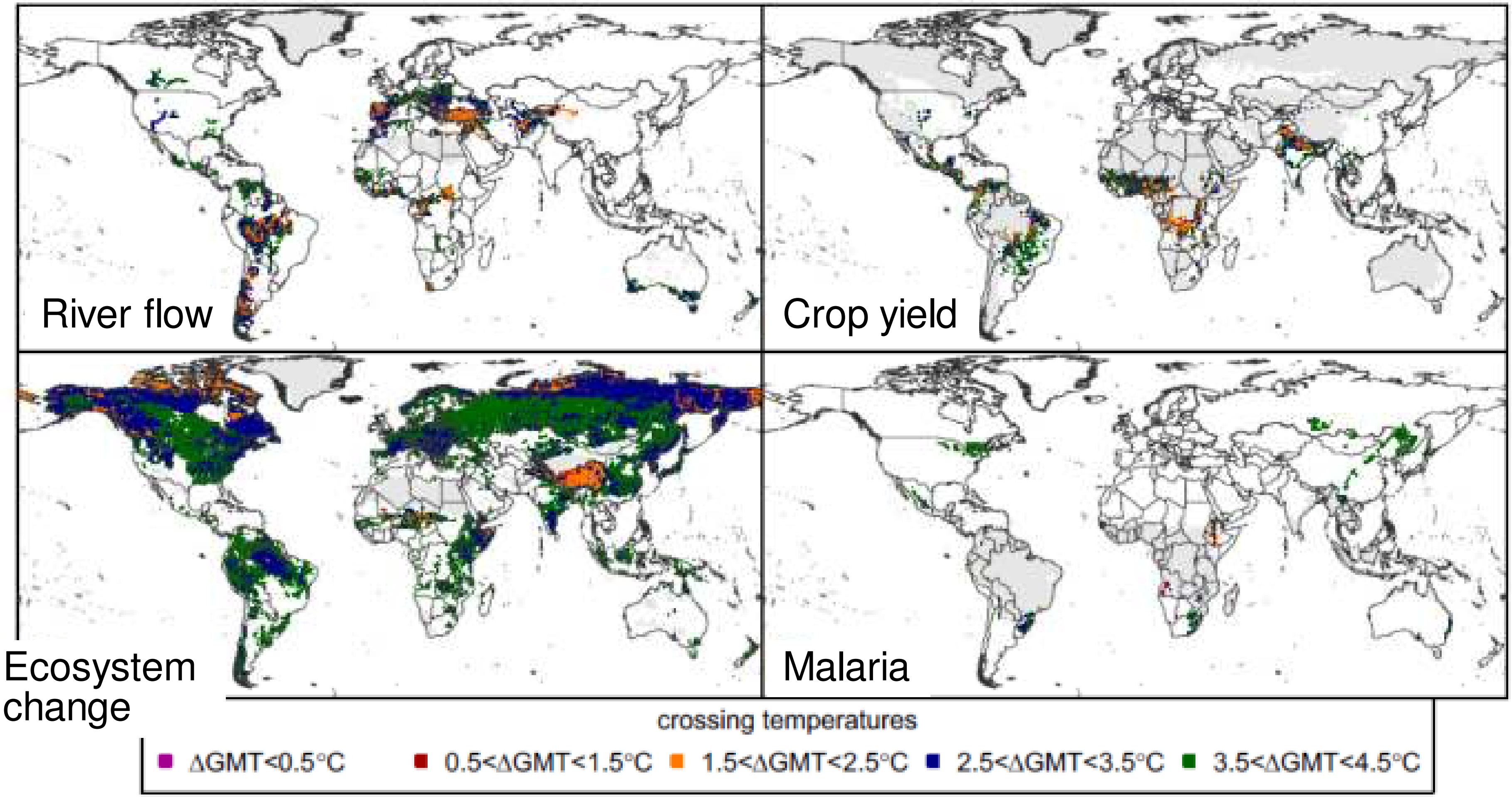
Stakeholder workshop,
**Eden Demonstration Test catchment,**
January 2014

http://nutcat2050.org.uk

# Food-energy-water-environment nexus: more sustainable futures, better representation of land in the earth system

# Nexus in ISIMIP?

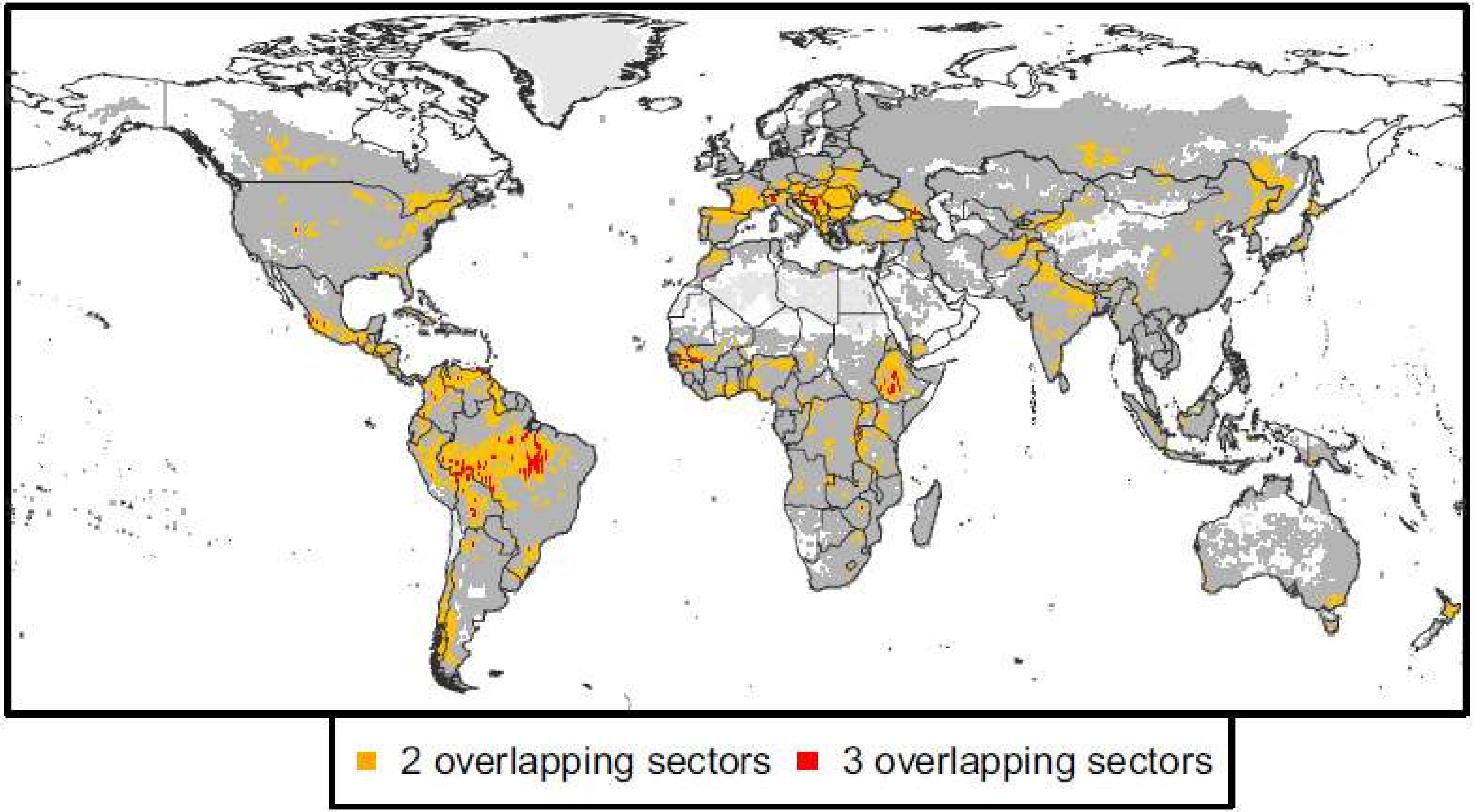
**Threshold crossing temperatures**:
severe change/high likelihood




Piontek et al. 2013

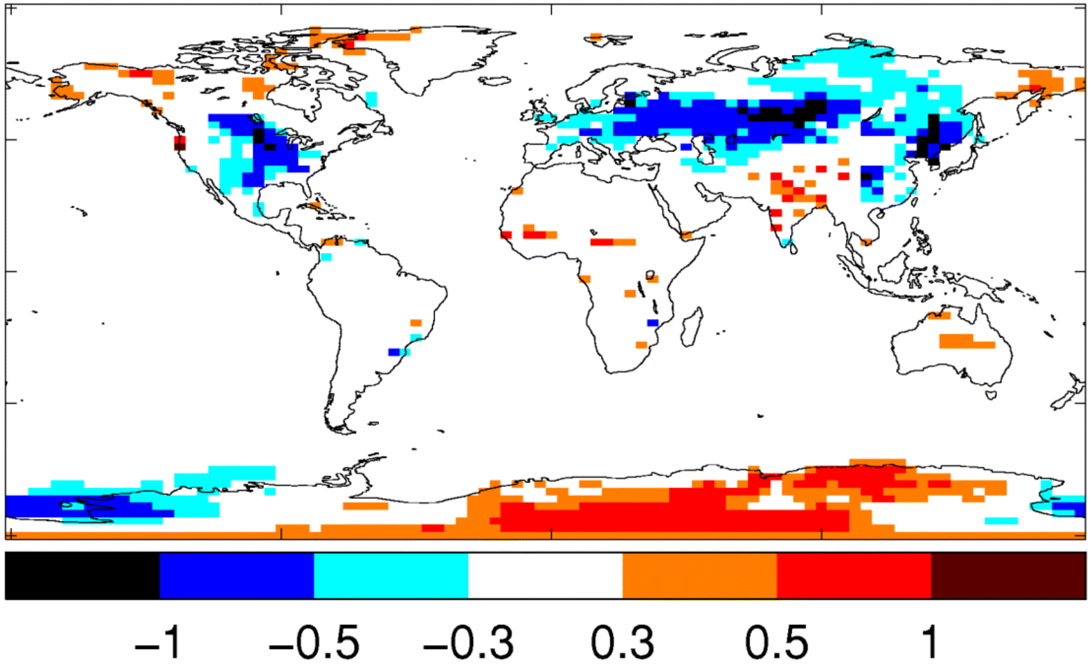
# Multisectoral hotspots:

## >50% of GIM/GCM combinations agree on threshold crossing for each sector, up to 4.5K GMT change



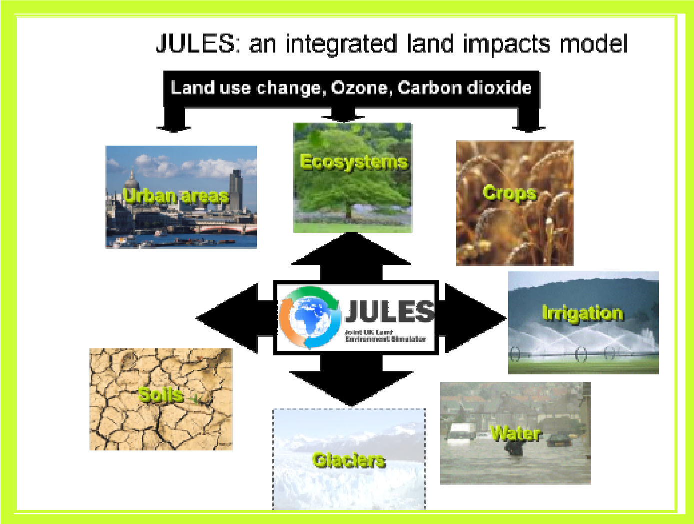

Piontek et al. 2013

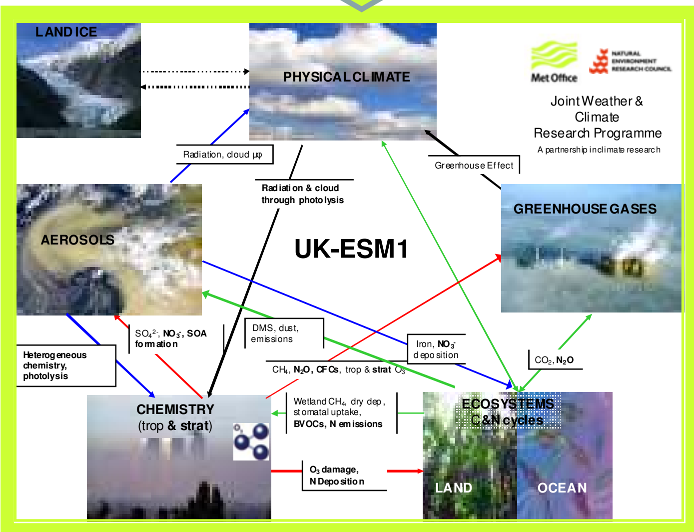
# Historic land clearance cools climate: **how does this differ in an ESM with crops?**




**Impact of actual-natural vegetation on surface temperature in an AGCM**

**Betts et al. 2007**



# Systems thinking in human-environment science

**(Nexus Network think piece, Macleod et al 2014)**

- **Why do we need nexus approaches?**
  - Urgently address complex global issues
  - Current solutions inadequate
  - Need novel systems-based holistic perspectives across research, policy and practice.
- **What are existing nexus approaches?**
  - Need to learn from implementation of these approaches, when they worked or failed.
  - Develop approaches that improve and add value to these existing approaches.

# Systems thinking in human-environment science

**(Nexus Network think piece, Macleod et al 2014)**

- **How do we carry out nexus approaches?**
  - Need awareness of the context e.g. politics.
  - Defining and framing the challenge and designing the approach are vital - focus on delivery of pragmatic &flexible solutions.
  - Wide collaboration that harnesses differences using negotiated methodologies.
  - Require individuals capable of integrative working.
  - Proof that nexus approaches are required by society and work.

# Conclusions

- **Climate change and variability could have significant impacts on food and water resources**
  - Strong regional differences
  - Uncertainty across scenarios, climate models, impact models...
  - Implications for agricultural management, trade and economics
- **Key challenges for future food and water:**
  - Impacts of extremes (crops, nutrients, erosion, flooding) – high resolution models
  - Climate variability and seasonal forecasts (limited skill in UK)
  - Confidence and uncertainty in impacts[1] – usability for decision making?
  - Overlapping priorities and links between sectors[2]: the food-energy-water-environment "nexus"

*[1]Falloon et al. 2014; [2]Falloon & Betts, 2010*