Quantifying Climate Change Impacts Water Resources: A Catchment and Global Analysis

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Reporting the work of many groups involved in QUEST:GSI project (PI Prof. Nigel Arnell, Walker Centre, University of Reading, UK

Water resources in developing countries: Planning and management in a climate change scenario, ICTP, 27th April-1st May 2009

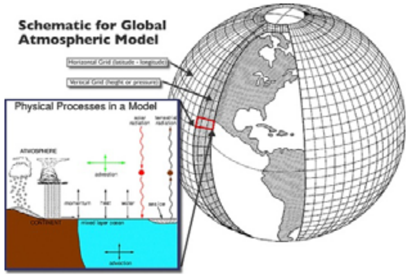
Quantifying and Understanding the Earth System

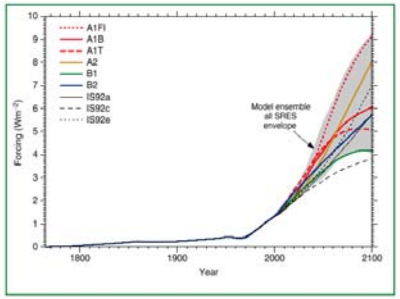
Presentation overview

- Overview of QUEST Global Scale Impacts project
  - Motivation and aims
- QUEST GSI water resource analysis
  - Methodology
- Results
  - Global scale analysis
  - Catchment scale analysis
- Conclusions and future challenges

Quantifying and Understanding the Earth System

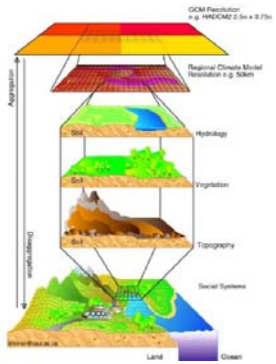
Recipe for climate change impact studies





1. **Take climate models with high UNCERTAINTY**

2. **Force them with highly UNCERTAIN boundary conditions**

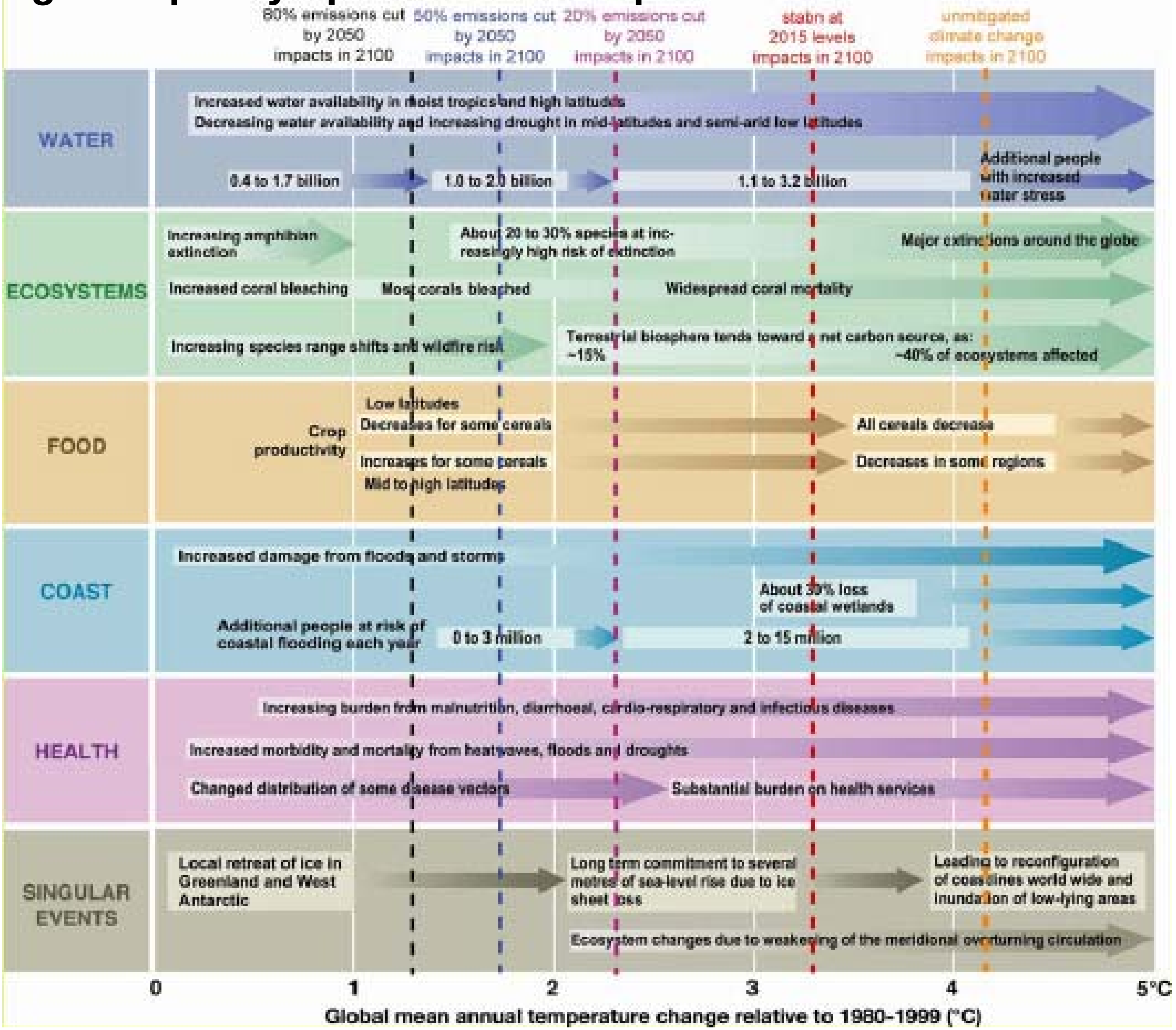


3. **Use UNCERTAIN GCM climate outputs to drive highly UNCERTAIN impact models**

4. **Give UNCERTAIN results to decision makers and run away**

Motivation for QUEST-GSI: IPCC AR4 WGII climate impacts & adaptation

Linking mitigation policy options with adaptation



To achieve this there is a need for a globally consistent assessment of climate change impacts across impact sectors

UCL

The NERC QUEST project

- QUEST: Quantifying Earth system processes and feedbacks for better informed assessments of alternative futures of the global environment.
  - Funded by UK Natural Environment Research Council

Theme 1
How important are biotic feedbacks to 21st century climate change?

Theme 2
How are climate and atmospheric composition regulated on time scales up to a million years?

Theme 3
How much climate change is
a) dangerous
b) can be avoided by managing the biosphere?

MarQUEST
Marine biogeochemistry and ecosystem initiative in QUEST
QUAAC
QUEST Atmospheric and Aerosols Chemistry
QUERCC
Quantifying Ecosystem Roles in the Carbon Cycle
Advanced Fellowship
High precision CO_2 measurements
CCMAP
Climate-carbon modelling, assimilation and prediction
Feedbacks QUEST
Quantifying the influence of biogeochemical feedbacks on climate change

Quaternary QUEST
Data synthesis and modelling for a full glacial cycle
PalaeoQUMP
Using palaeodata to reduce uncertainties in climate prediction
QUEST Deglaciation
Climate and biogeochemical cycles during the last deglaciation
DESIRE
Anglo-French collaboration on ES dynamics in ice cores
Dynamics of the PETM
Relevance of the Paleocene-Eocene thermal maximum to future global change

QUEST GSI
An assessment of global scale impacts of climate change
QUATERMASS
Quantifying the potential of terrestrial biomass to mitigate climate change
JIFor
Providing a scientific basis for a JI forestry demonstrator climate mitigation project
QUEST Fish
Predicting impacts and consequences of climate change on fisheries
FireMAFS
Fire modelling and forecasting system

6 UK institutes
2006-9

Cross Cutting and Integrative Activities
-------------- **Working Groups** --------------
Abrupt climate change, Adaptation and the Coastal Zone, Avoided deforestation, Biodiversity and climate change, Boundary layer processes, Climate change and carbon in uplands, Climate prediction for robust policy making, Dust and climate, Grazing systems, Fire, Green Ocean modelling, Human dimensions of ESM, Hydrological cycle, Plant functional classification, Pinatubo Interdisciplinary Multi-Model Study, PMIP, QUAVIDA, SEDMIP, Sustainable biofuels, Visualisation
------------------**QUEST Earth System Model**------------------
A new fully coupled ESM of intermediate resolution

NATURAL ENVIRONMENT RESEARCH COUNCIL

QUEST Quantifying and Understanding the Earth System

QUEST GSI Aims:
http://www.met.reading.ac.uk/research/quest-gsi/

- To quantify the impact of different degrees of climate change on a wide range of ecosystem services globally

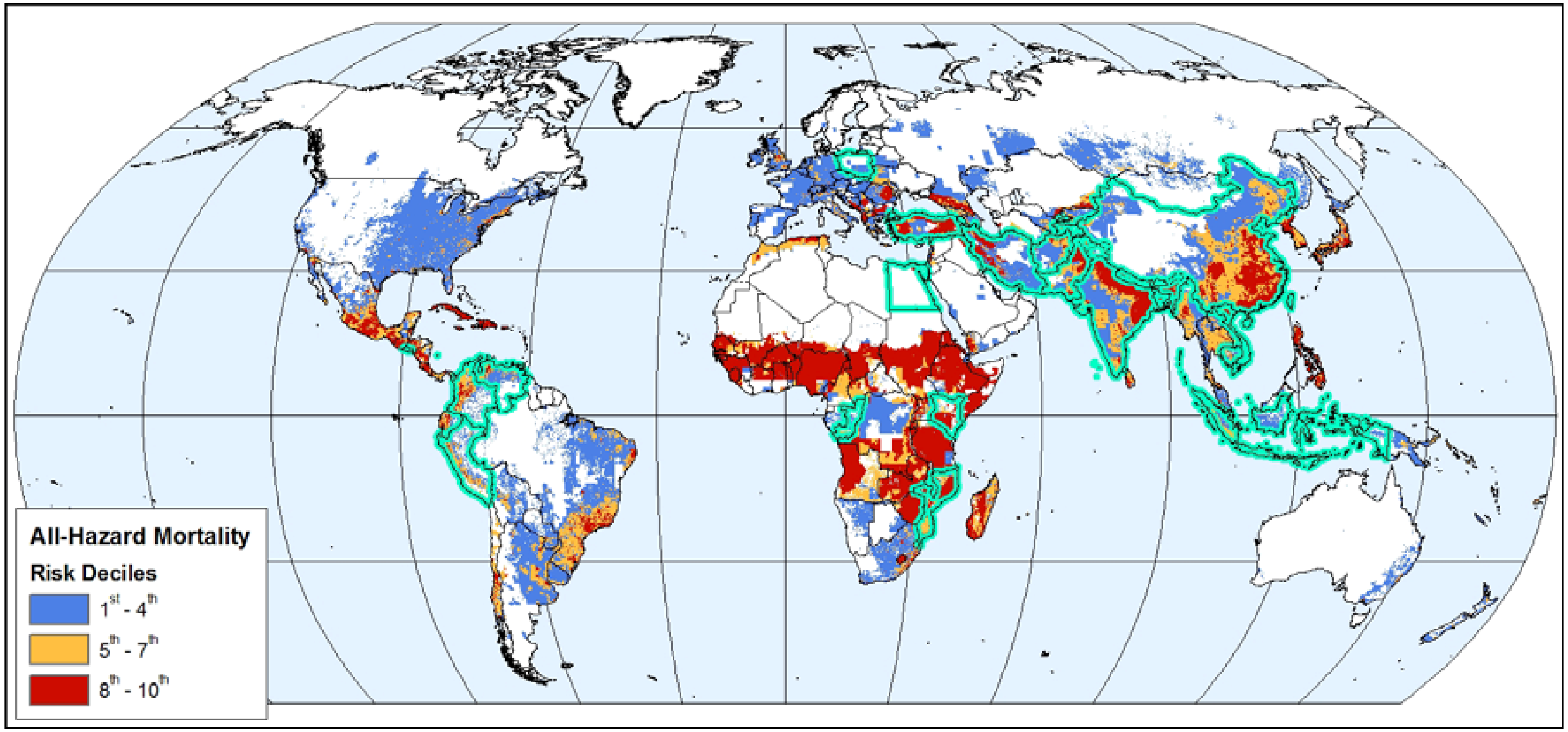
- To provide a consistent framework for assessing the impacts of specific climate policies
  - SRES scenarios, 2^{o}C target etc

- Multiple sectors:
  - **Water resources**, Coastal flooding, Fluvial flooding, Crop productivity, Ecosystem productivity, Carbon storage in soils, Aquatic productivity

- To help inform policy
  - Mitigation : What is the relationship between mitigation policy and cost?
  - Adaptation e.g. water resource planning

Final outcome will be multi-sectoral syntheses of climate change impacts

Figure 9. Mortality risk hotspots and the top 20 recipients of humanitarian relief (1992-2003).



e.g. Columbia Hotspots project

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- *QUEST GSI water resource analysis*
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Quantifying and Understanding the Earth System

QUEST GSI: Experimental design summary

Drive impact models with estimates of future climate and associated uncertainty

1. **Multiple scenarios**
   - **Emissions-based (IPCC SRES)**
   - **Prescribed-temperature change scenarios**
     - **To produce climate impact response functions**

2. **Uncertainty: Ensemble approach**
   - **GCM uncertainty**
     - **AR4 models (n=18),**
     - **HadCM3 QUMP perturbed physics ensemble (n=17)**
   - **Impact model uncertainty**
   - **Socio economic uncertainty**

Future climate data using pattern scaling

Rationale: (i) convenient (ii) globally consistent approach (iii) facilitates prescribed warming scenarios

Create scenarios by *pattern-scaling* climate model output

1. Determine pattern of climate change for each GCM and climate variable T, P, WV, cloud, wind (from A2 run 2070-99)

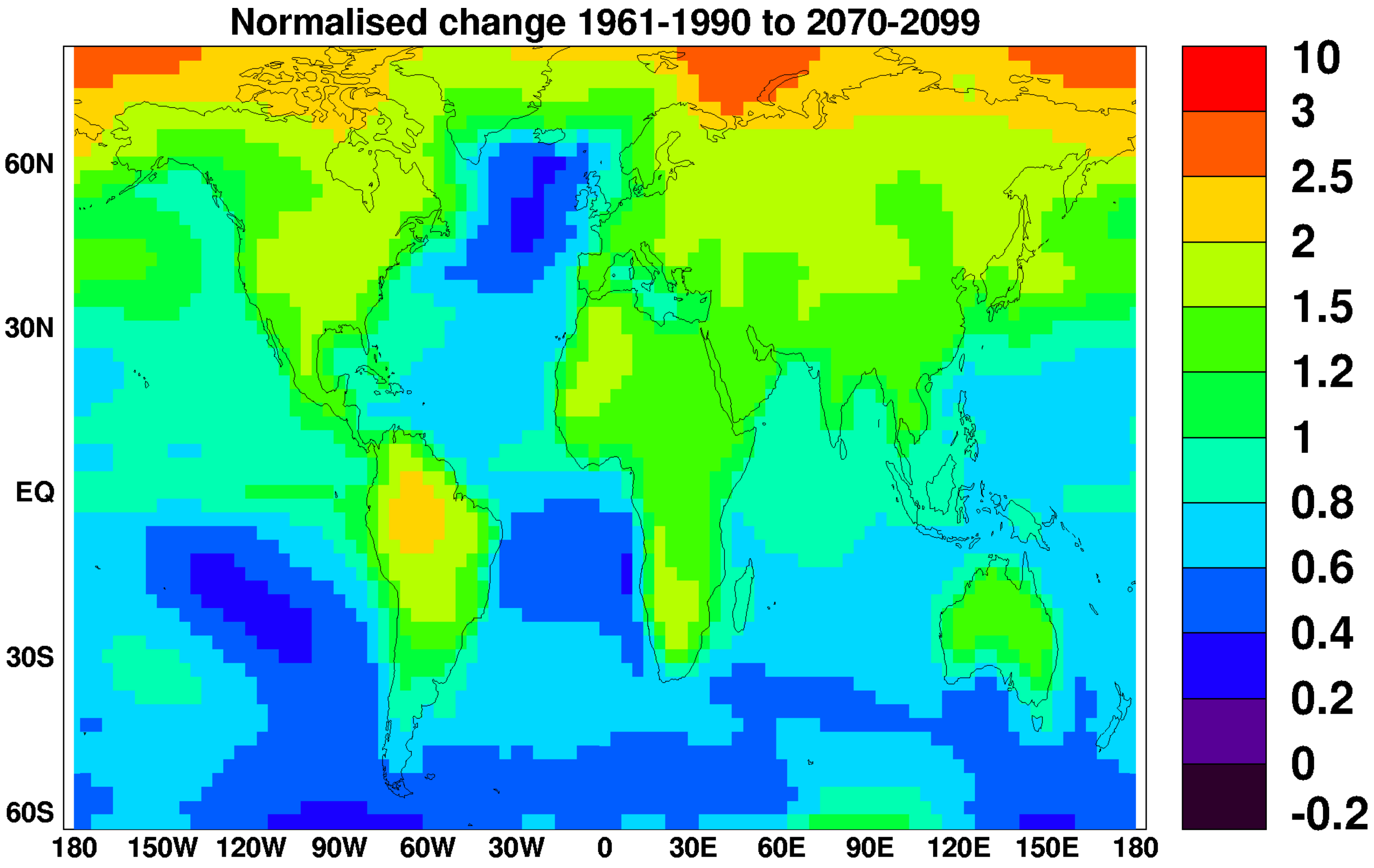
2. Scale for global mean temperature

3. Add the scaled climate changes to an observed gridded climate data set (CRU TS3.0 0.5 degree global gridded data)

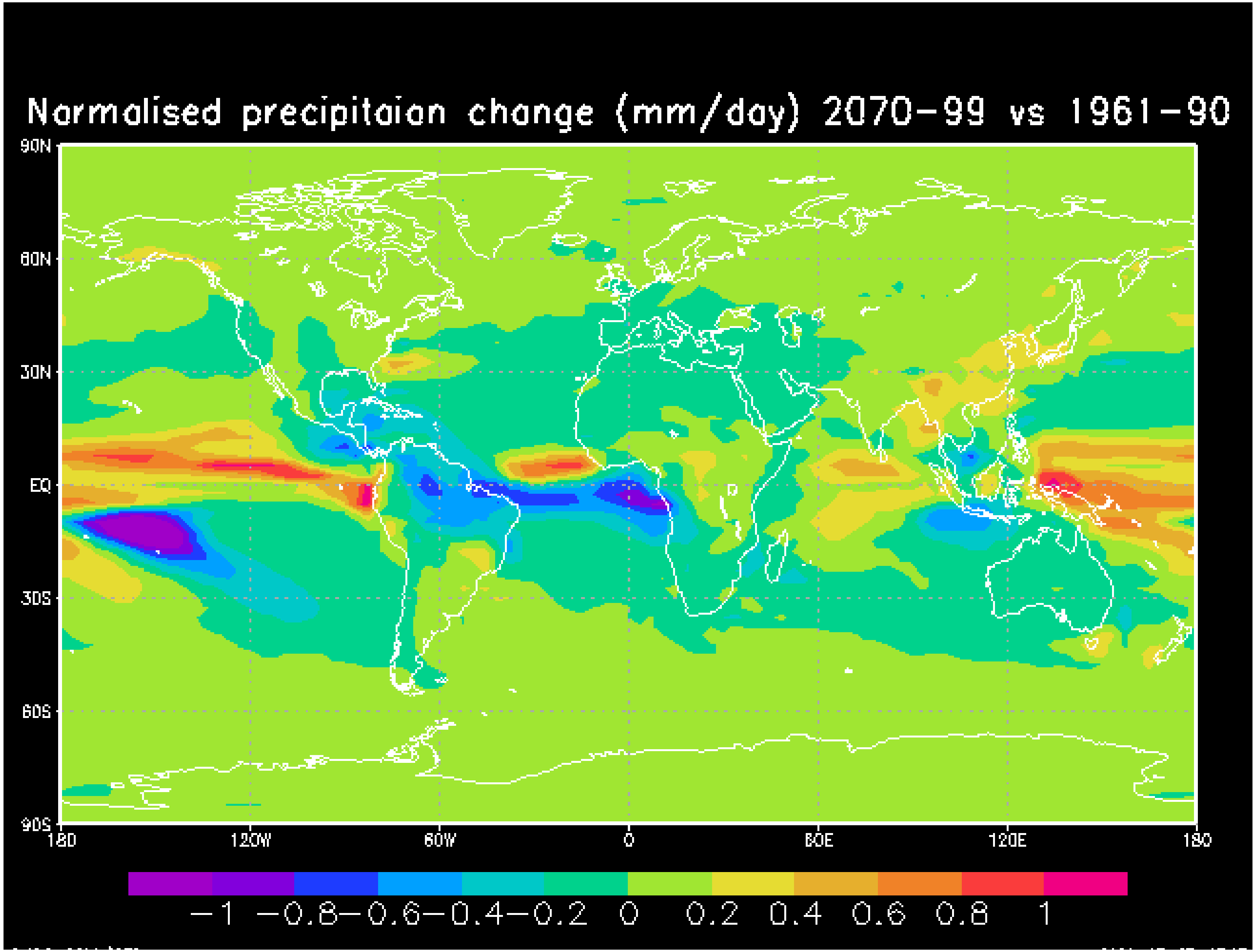
(Preserves year-to-year and decade-to-decade variability in the original time series)

Executed using the ClimGen software developed by Tim Osborne at Climatic Research Unit (CRU) at University of East Anglia (UEA), UK

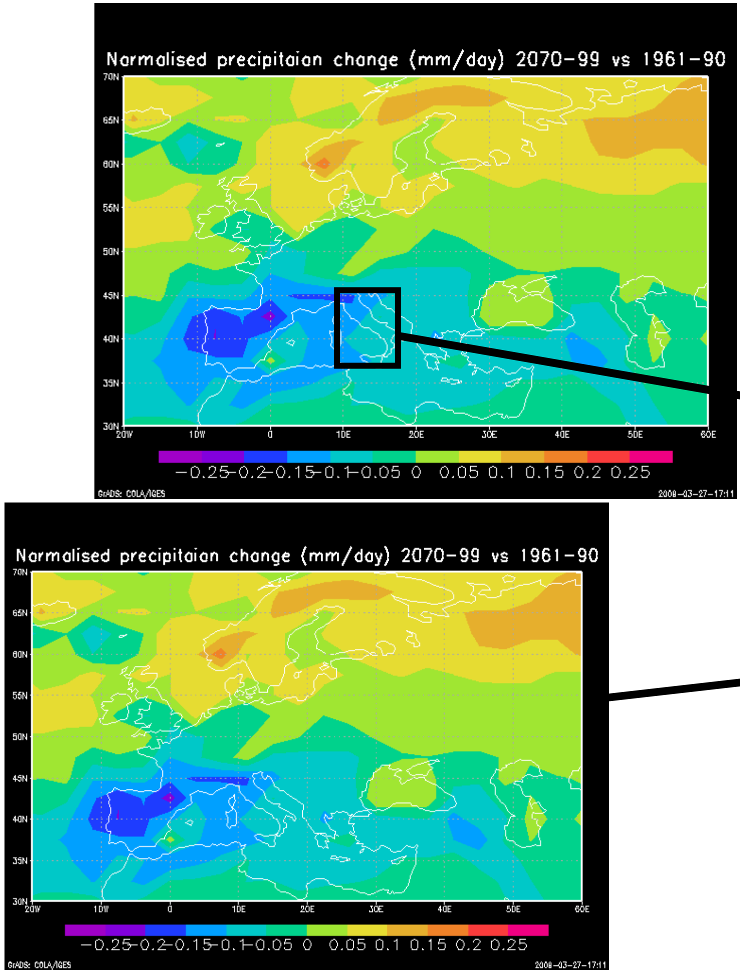
HadCM3 A2 temperature change by 2080s divided by global temp change



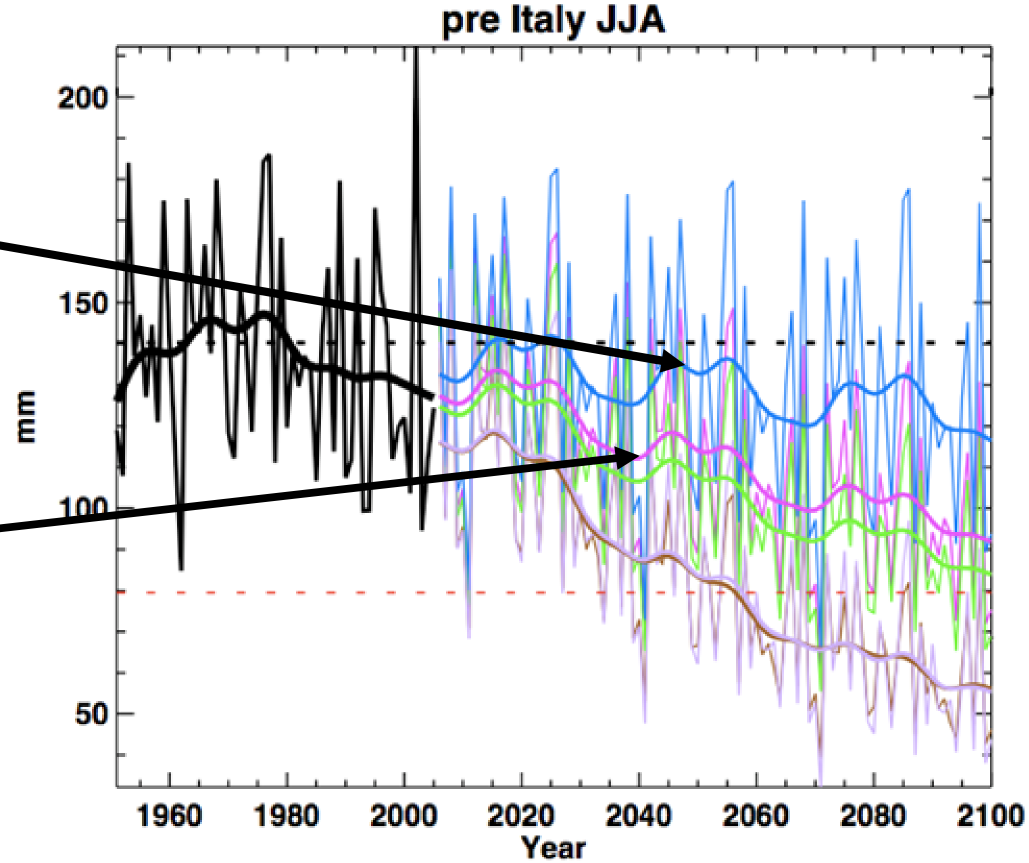
Pattern scaling for precipitation



Example



Historical timeseries at each global grid cell is perturbed with change in mean and variance from pattern scaled GCM



Pattern scaled precipitation signal for ensemble of multiple GCMs

- **AR4 GCMs (n=18)**
- ***HadCM3 QUMP (perturbed physics) set (n=17)***

Advantages/Limitations of method

- Advantages
  - Convenient
  - Globally consistent
  - Allows calculation of climate change signal for different degrees of 'prescribed' warming
  - Easy to account for GCM uncertainty
- Disadvantages
  - Assumes linear dependence of magnitude of climate change pattern on global mean temperature
  - Downscaling is simple interpolation of GCM climate change pattern

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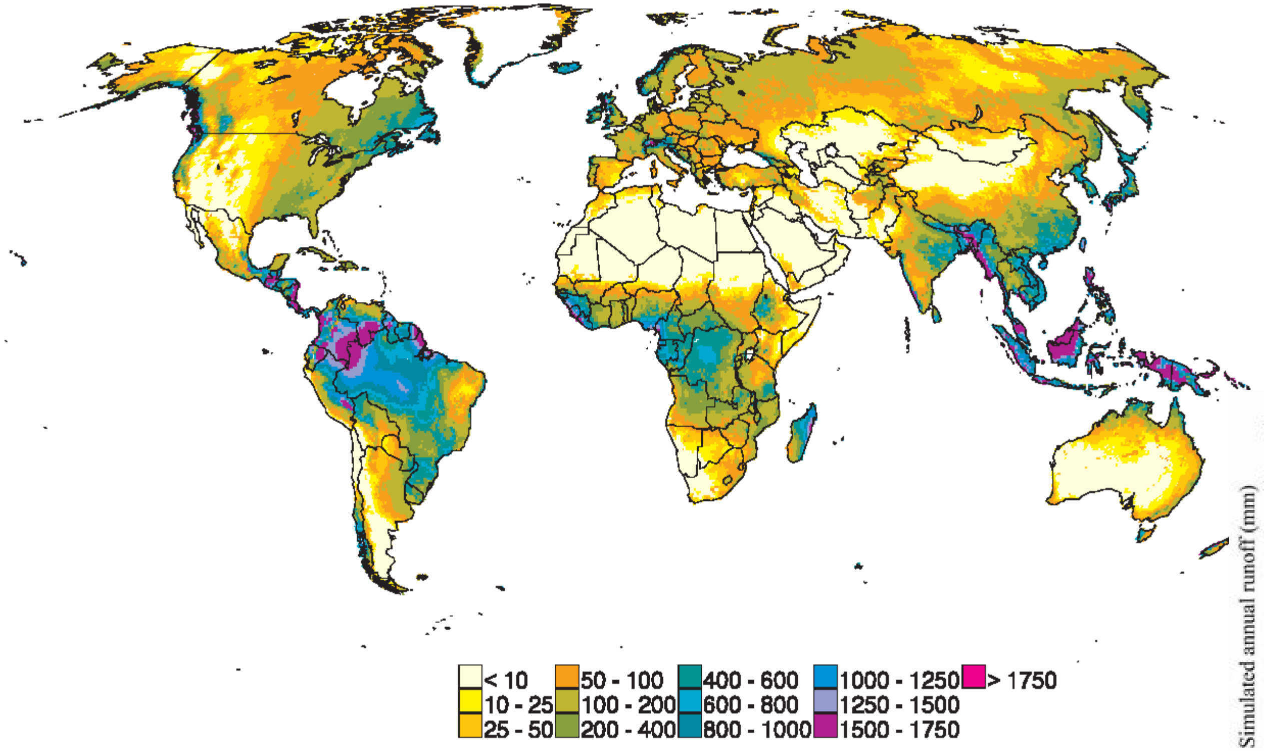
Macro-scale global hydrological model

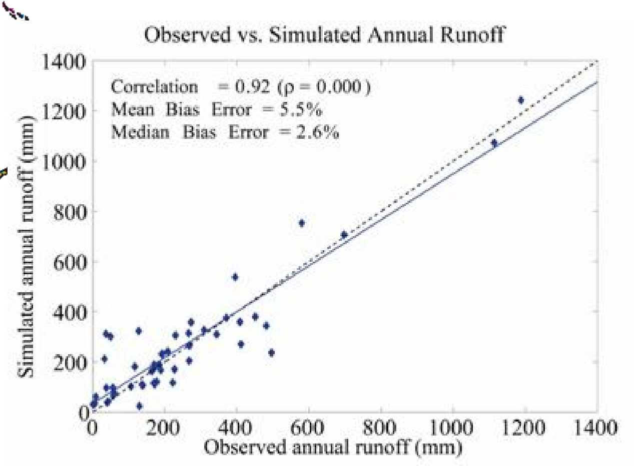
MacPDM (developed by Nigel Arnell, University of Reading, UK)

- daily water balance accounting model
- 0.5 degree model grid resolution
- parameters estimated from spatial data sets (soil, vegetation)
- Driven by CRU TS 3.0 monthly data (weather generator for daily data)
- PE estimated using Penman-Monteith
- soil moisture characteristics vary within grid cell
- no routing from cell to cell
- not calibrated at the catchment scale

Arnell, 2004

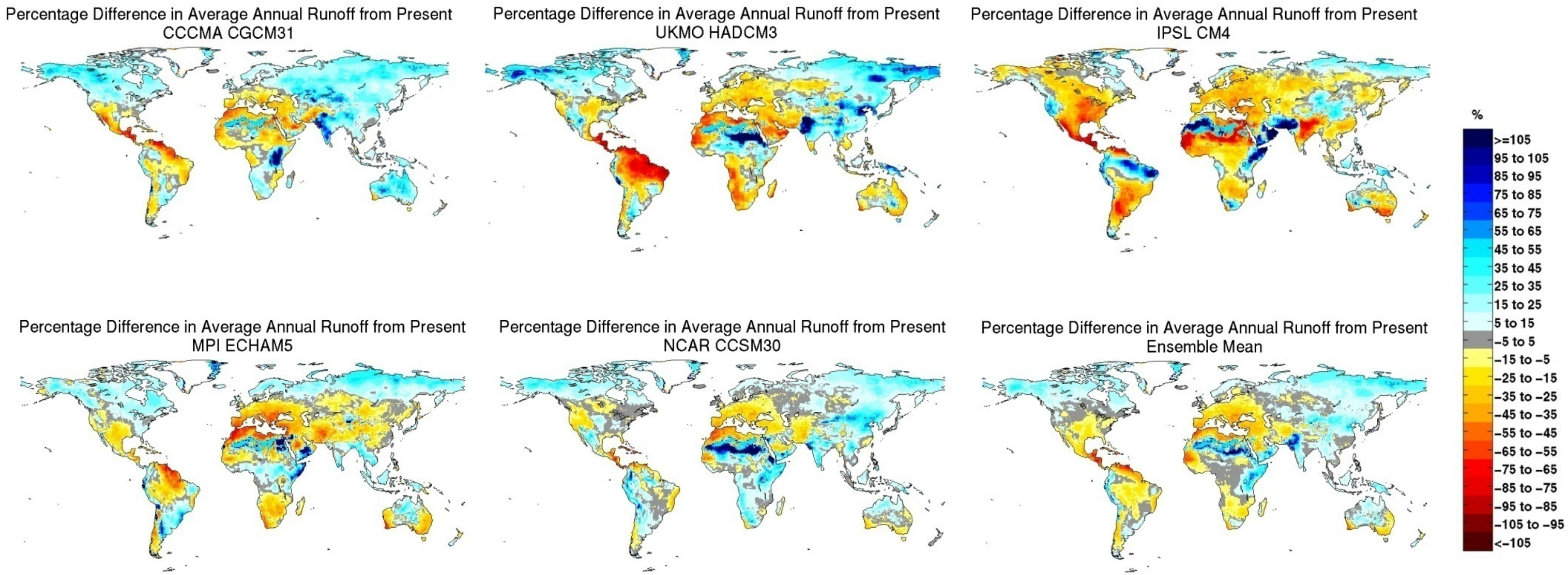
MacPDM performance: Global mean runoff





Tends to overestimate runoff in dry regions – evaporation of runoff and transmission loss not adequately accounted for (see presentation by Wheater on Monday)

Results: Change in runoff under A1b emissions (2050-80 minus 1961-90)



- **Substantial uncertainty in response between GCMs especially in tropics**
- **Will calculate probability distributions of runoff change from multi-model ensemble simulations**

Indicators of water resources stress

Indicator = **water resources per capita by watershed**

Indicator *of* ***impact*** *of climate change*

= populations living in *water-stressed* watersheds, where runoff decreases *significantly*

Water-stressed: *< 1000m³/capita/year*

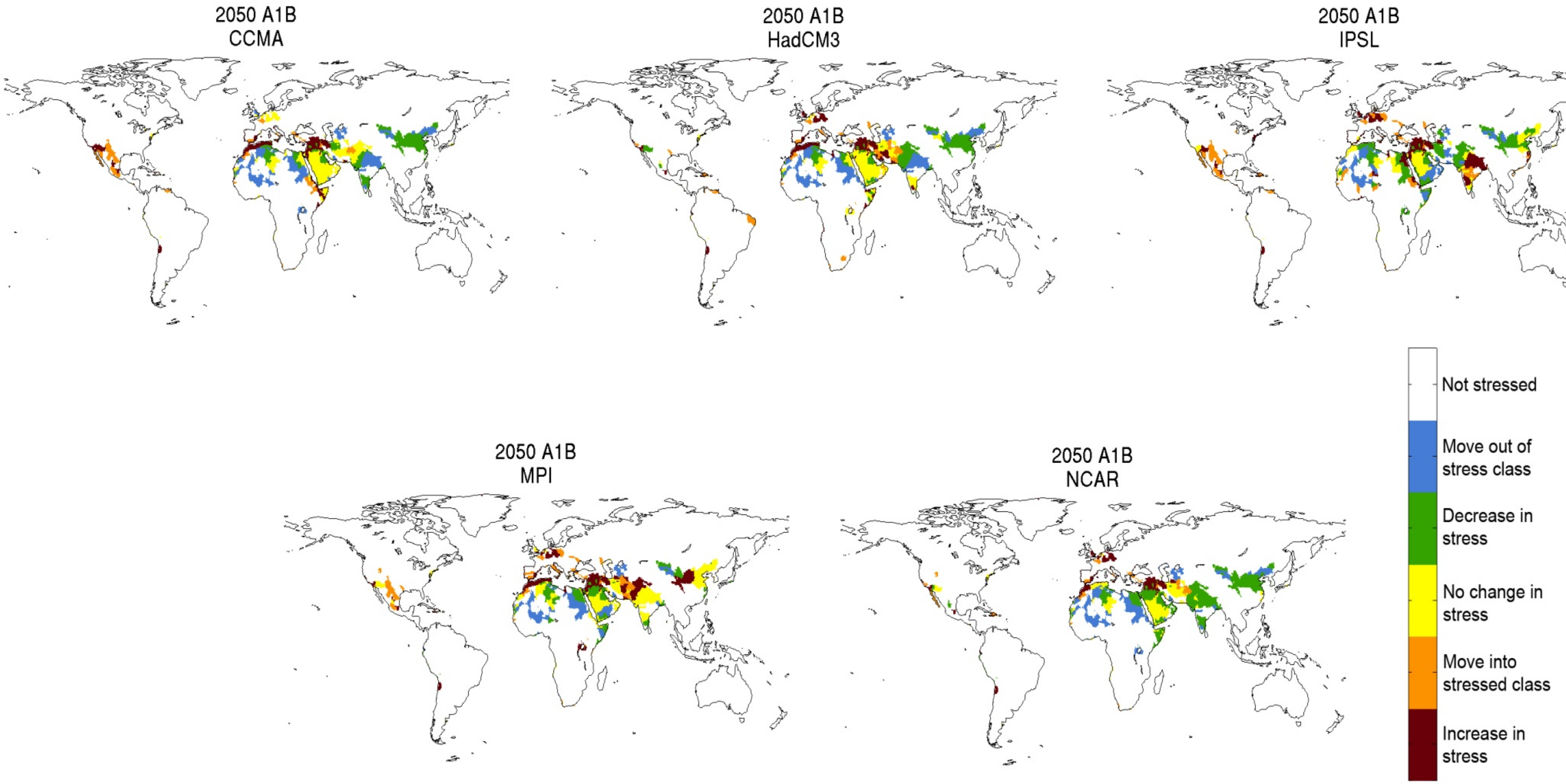
"significant decrease": decrease in runoff greater than standard deviation of 30-year mean runoff

But takes no account of

- Basin storage e.g. in much of Africa soil water store supports agriculture
- Different rates of water use (i.e. withdrawals)

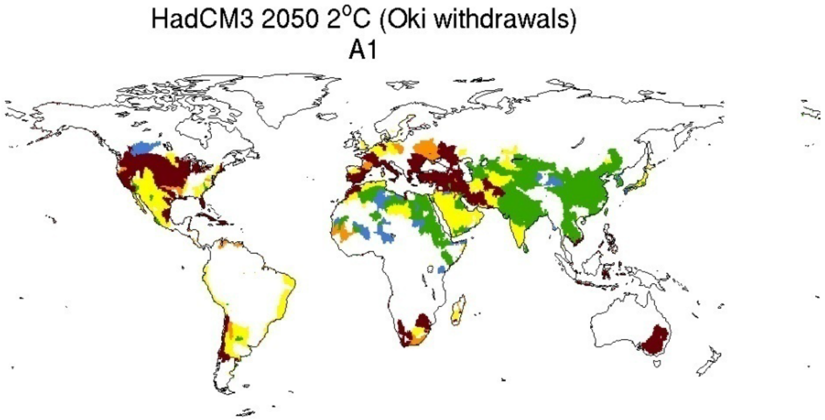
Distribution of water stresses

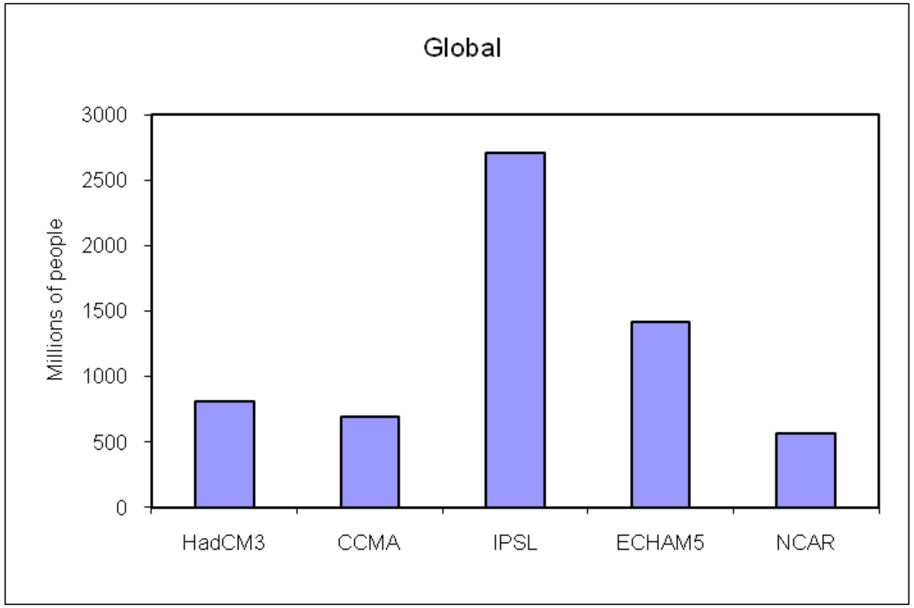
A1b 2050 – core models



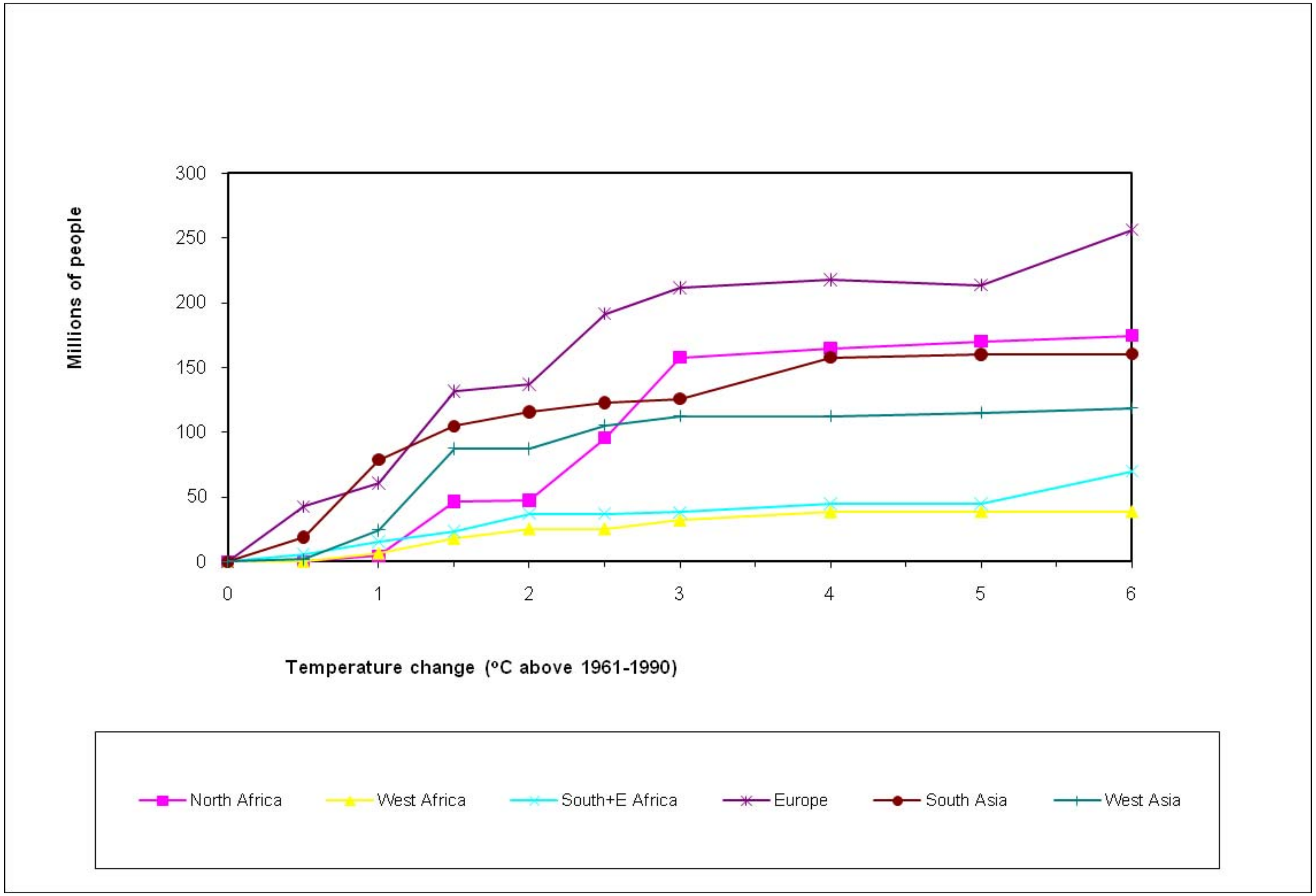
Distribution of water stresses

A1b 2050 – core models





Regional climate impact response function



Characterising adaptation

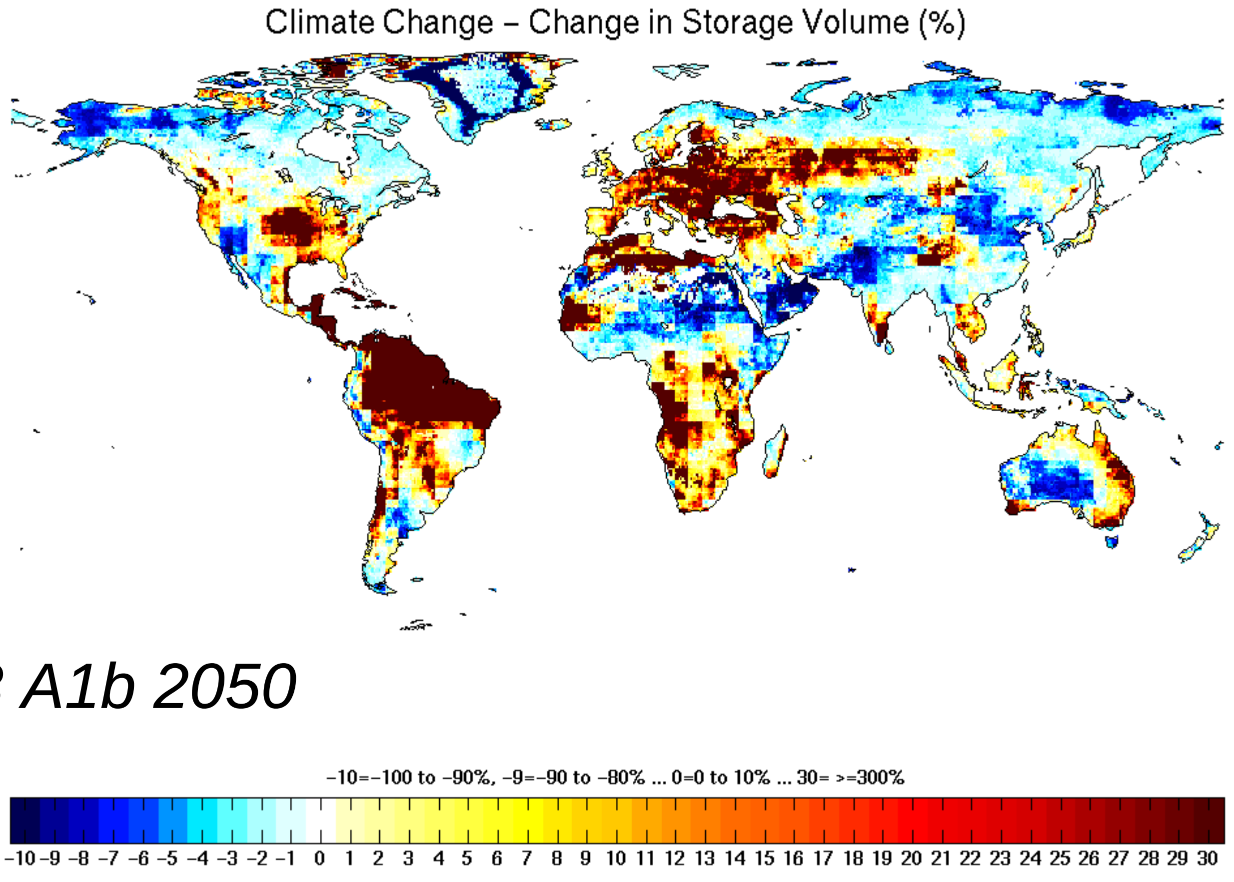
How can we characterise adaptation across a large domain?

- Adaptation options and feasibility vary with local context

At each grid cell impose a hypothetical reservoir with defined yield (75% of mean flow) and reliability (90%)

Indicator of impact – change in volume

Change in volume to maintain target yield and reliability



HadCM3 A1b 2050

Global scale analysis: Conclusions

- Broad-scale approach to estimating climate change impacts on river runoff and water resources stresses
  - Determine Climate Impact Response Function to help define levels of ‘dangerous climate change’
  - Quantify uncertainty
- Applied generalised approaches to characterising adaptation
- Initial results only so far

But adaptation strategies to climate change will generally be developed at the catchment scale…

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    - Mekong river
    - Rio Grande
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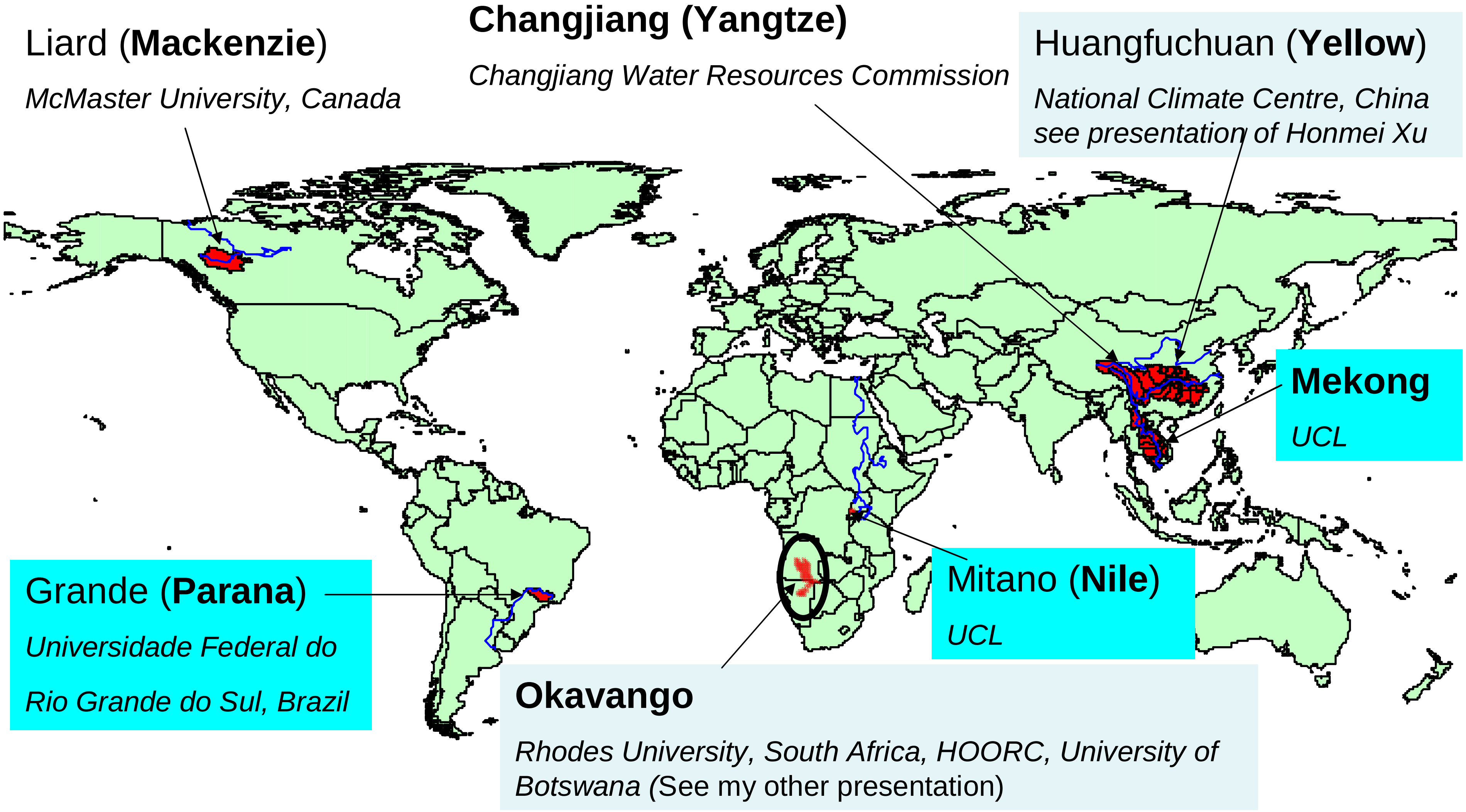
Quantifying and Understanding the Earth System

Catchment-scale studies



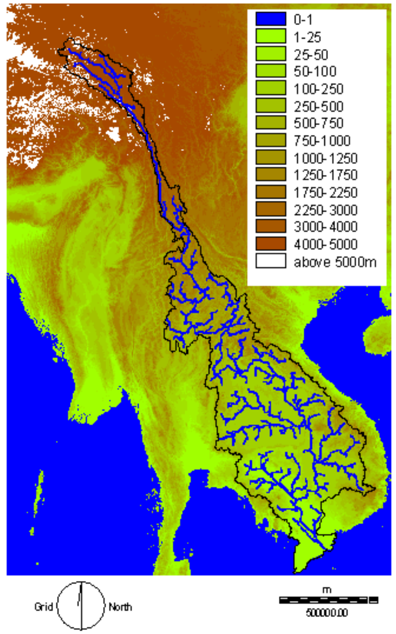
•Network of basins to represent a range of physical and human environments

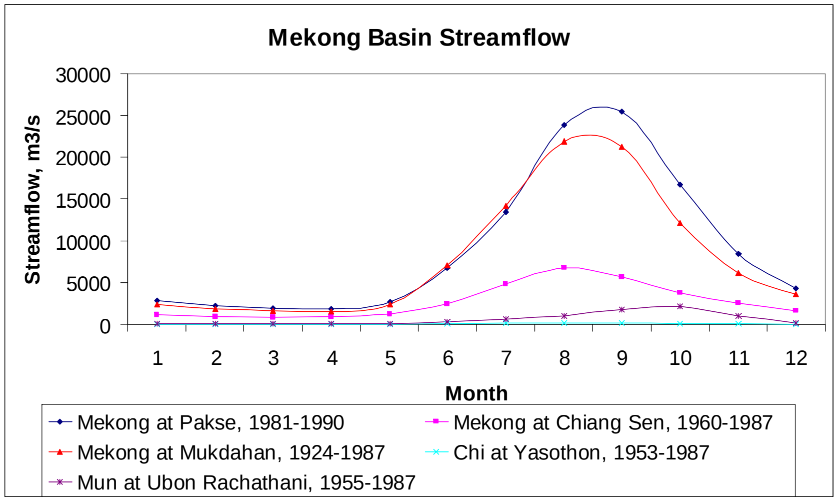
Catchment scale analysis

- Provides comparison with global hydrological model
  - More sophisticated basin hydro models
- Facilitates much more precise estimates of water scarcity
  - Current measures of “water scarcity” do not inform adaptation
- Case studies for adaptation policy

Climate change impacts on the Mekong River

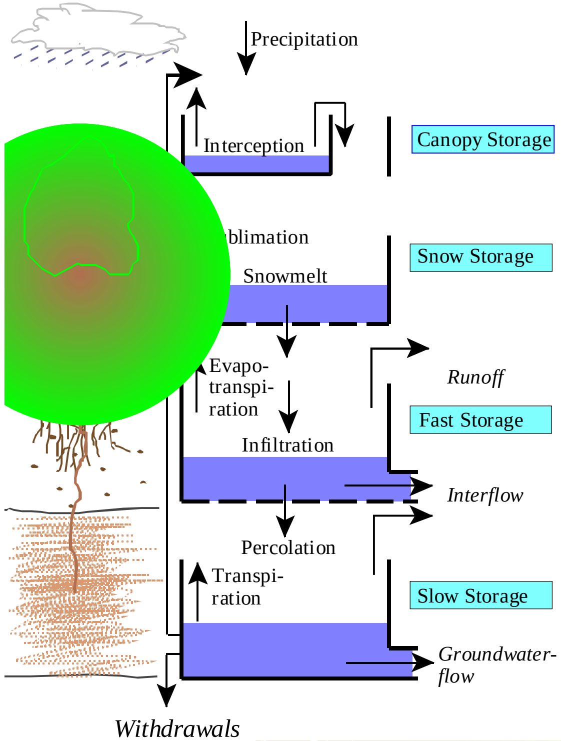
- 795,000 km^{2}, 4200km long, Mean total annual discharge = 475bn m^{3} (6th largest in world)
- Climate: Summer SW monsoon rainfall
- From Tibetan plateau (>5000m) to Vietnam and South China Sea
- China, Burma, Thailand, Laos, Cambodia & Vietnam
  - ~ 50 million people
- Socio-economic importance:
  - Fish:
    - 700,000 tons, 300 species p.a. (1992)
    - Fish are 50-80% total protein intake
  - Agriculture
  - Hydropower



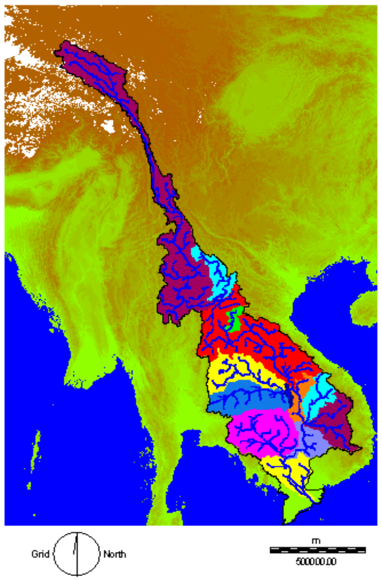


Hydrological model

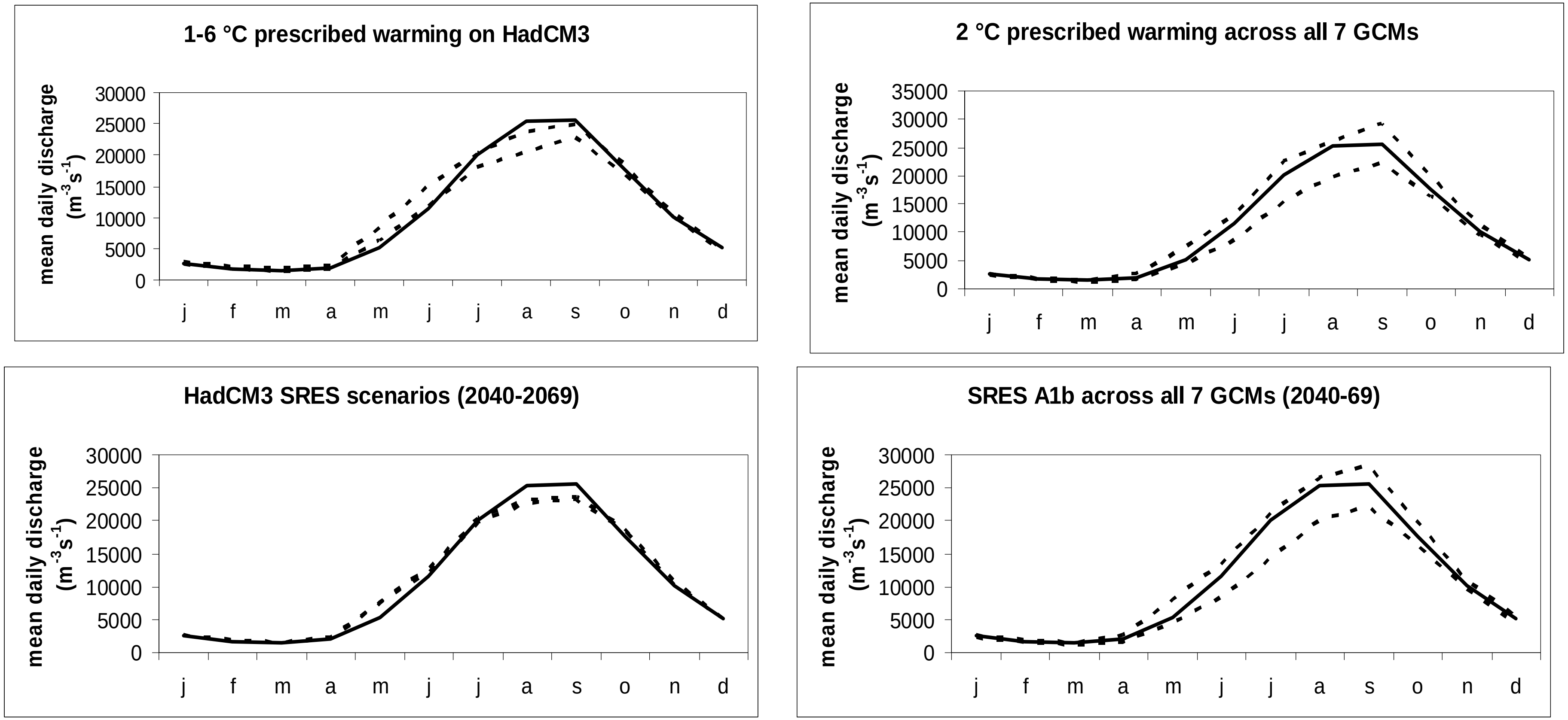
- SLURP (Semi-distributed Land-Use Runoff Process) model
  - Semi-distributed, physically based
  - Kite, G. (2001) *Journal of Hydrology*, 253 pp1-13.



- 13 sub-basins derived from DEM
- Sub-basins further divided, based on land-use (9 categories)
- FAO world soil map
- Model driven by CRU TS3.0 monthly data downscaled to daily with weather generator
- Et derived using Linacre method



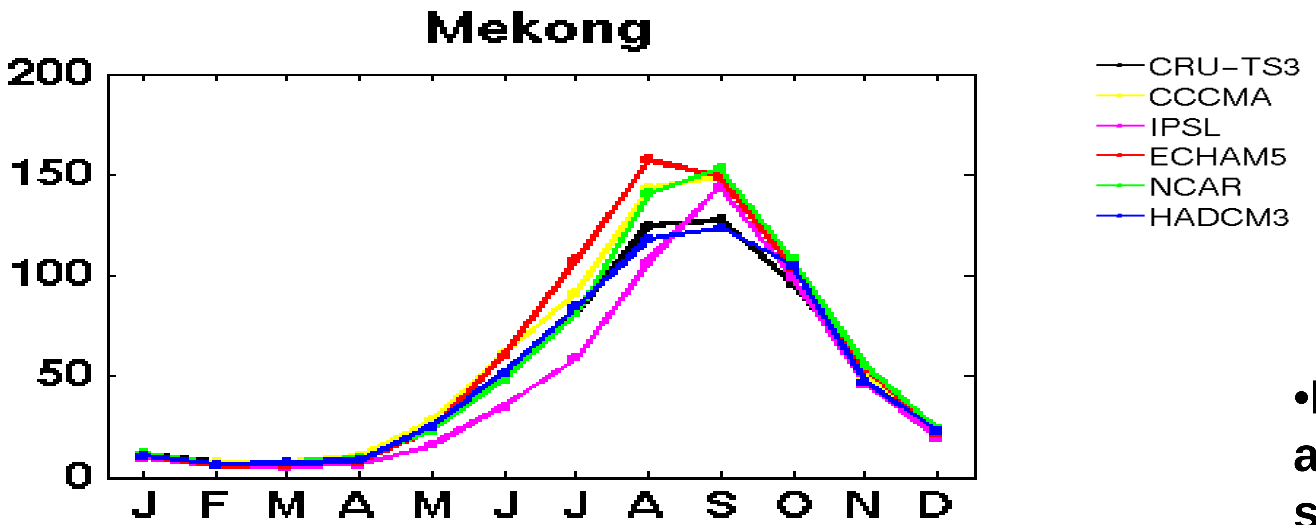
Summary: Uncertainty envelopes

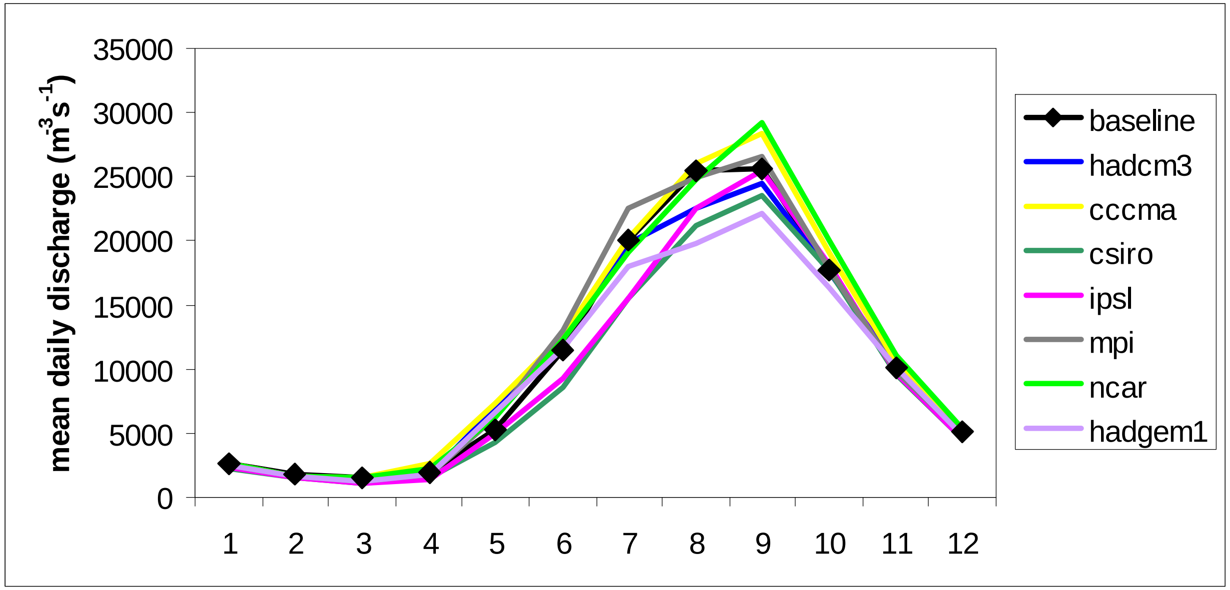


Uncertainty associated with GCMs greater than that from SRES emission uncertainty and is greater than magnitude of impact over 1-6C global warming

Comparison of Global model (MacPDM) and catchment model

2050s runoff change from present – A1B models





- **Relative change across GCMs is similar between the global and catchment models**
- **Magnitude of change differs**

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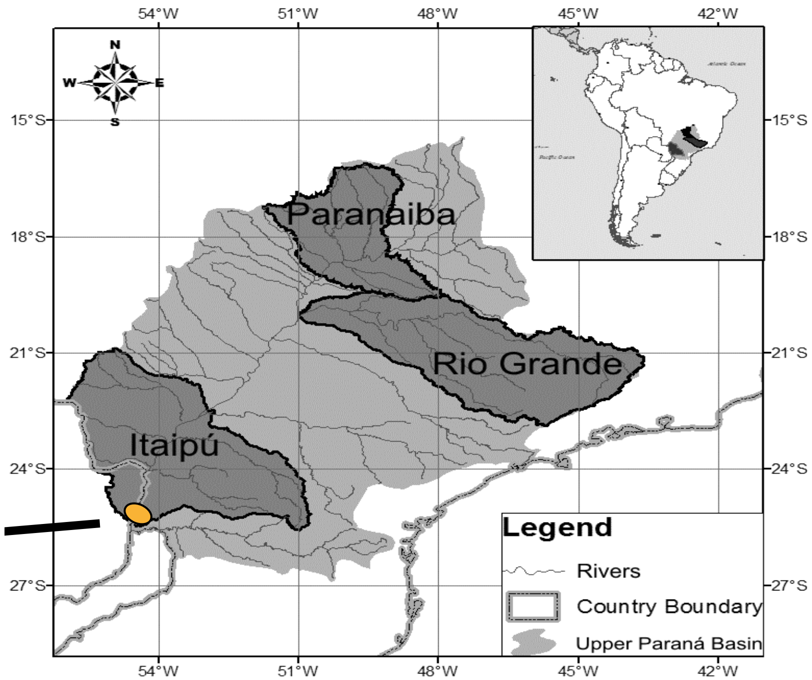
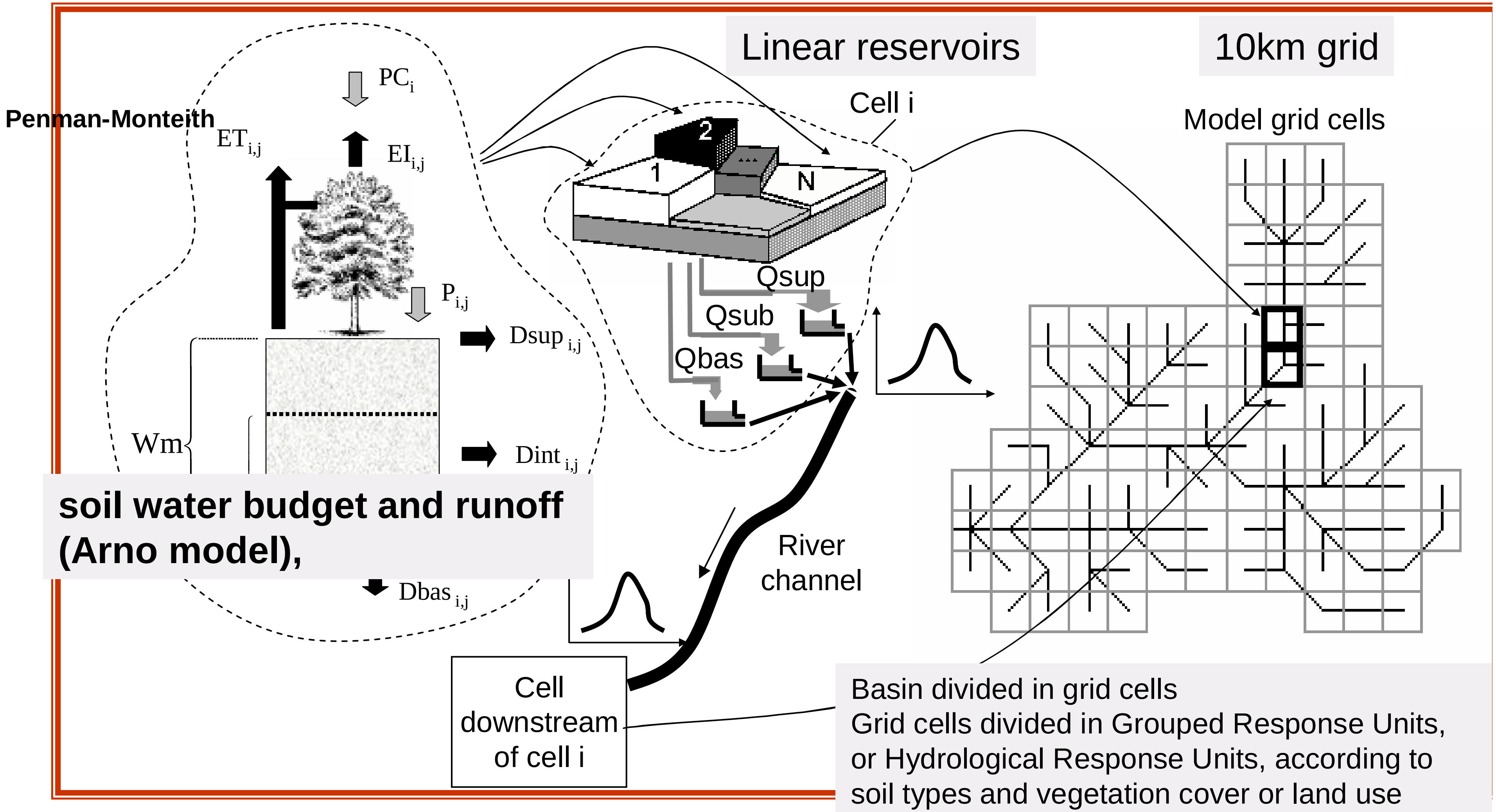
Impact of climate scenarios on freshwater resources in the Rio Grande - Brazil

Márcio Nóbrega and Walter Collischonn, IPH UFRGS



- Triburtary of Parana river
- drainage area: 145000 km2
- Hydropower is the most important source of electric energy in Brazil
- 60% of hydropower production in Brazil comes from the Paraná river and its tributaries. Rio Grande provides 16% of total
- One of the largest river regulation reservoirs (Furnas) is located on the rio Grande
- Itaipu dam

The MGB-IPH large scale hydrological model (similar to VIC)

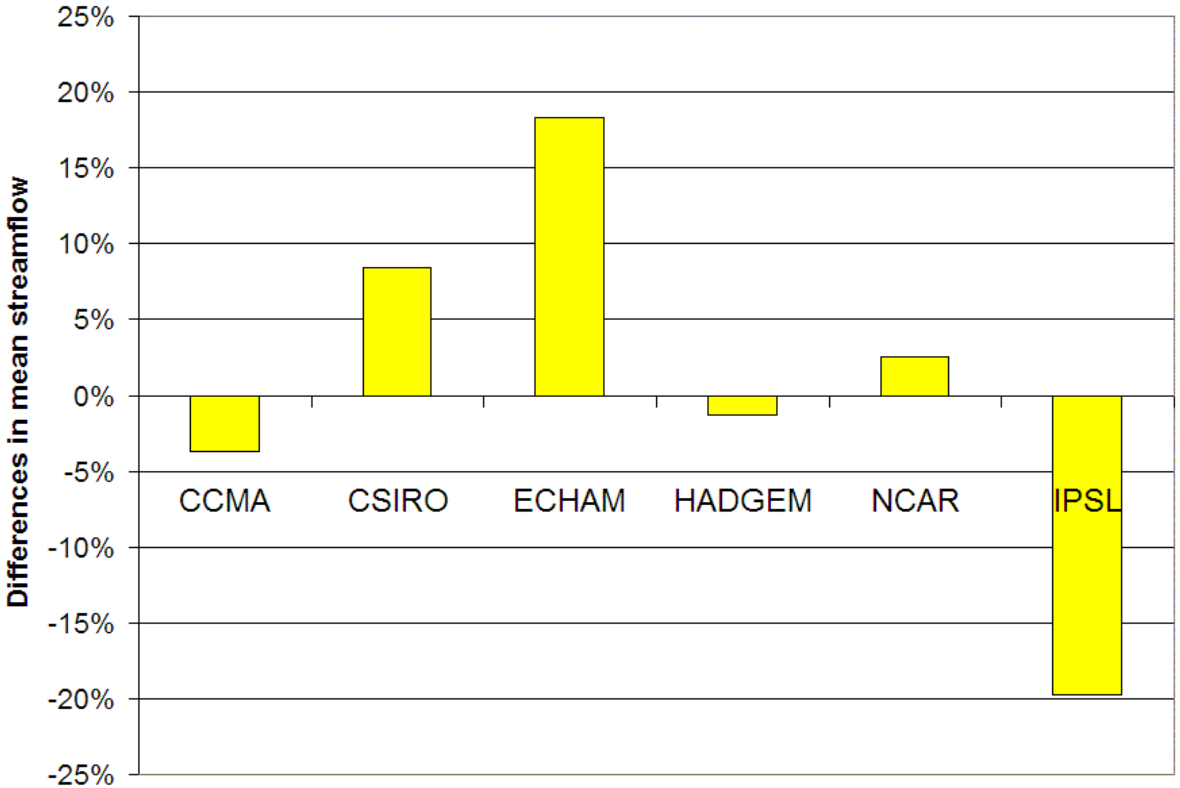


Basin divided in grid cells
Grid cells divided in Grouped Response Units, or Hydrological Response Units, according to soil types and vegetation cover or land use
Parameters are related to GRUs and can be calibrated

Calibrated with CRU TS3.0 gridded data

SIMULATED CLIMATE CHANGE IMPACTS: GCM uncertainty

Relative differences between GCMs in +2°C scenarios and detrended series

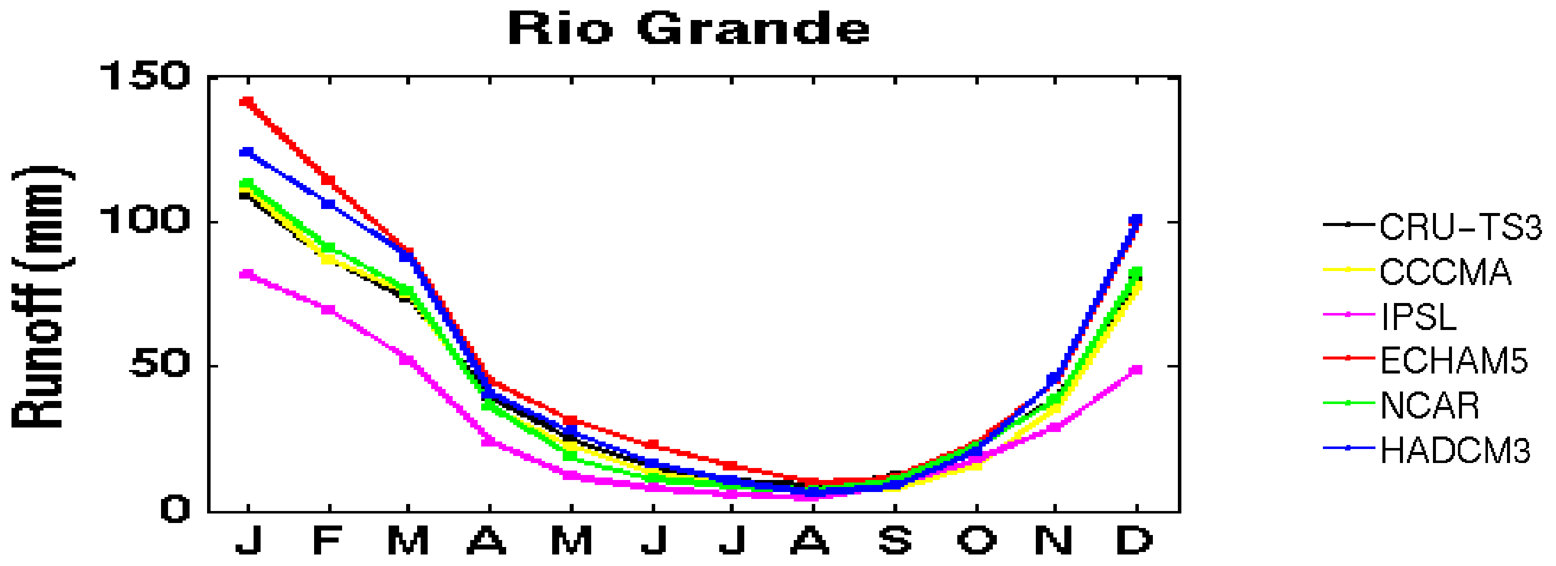


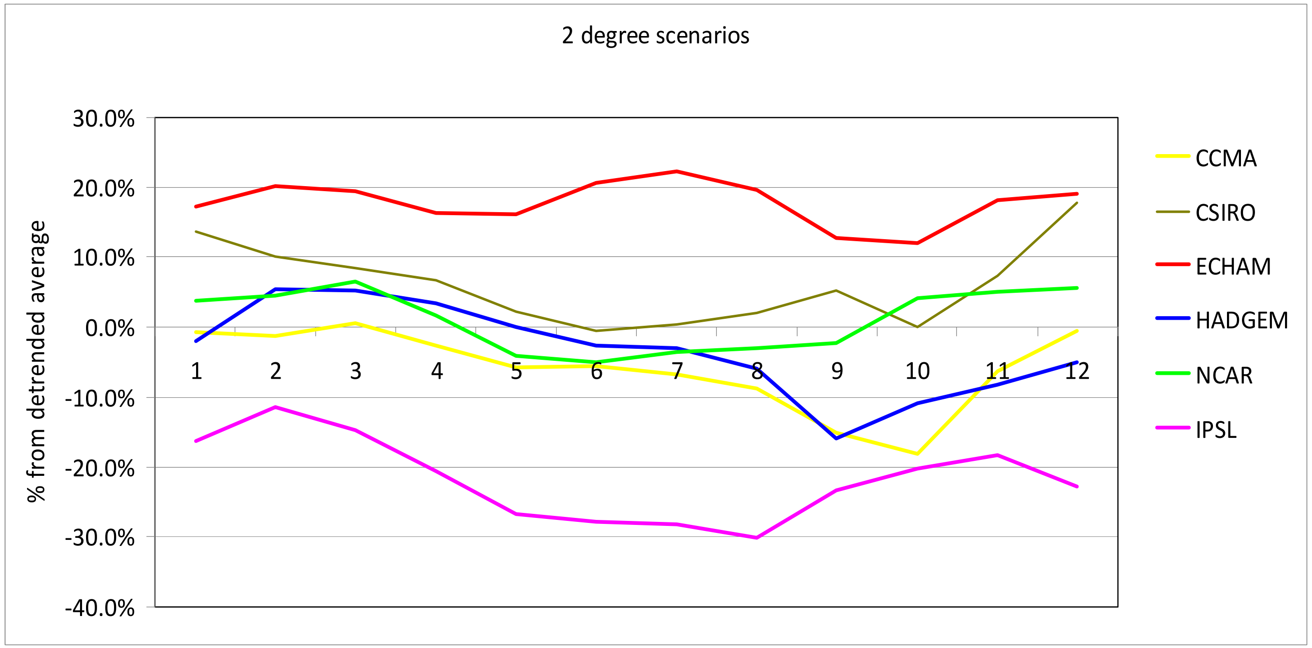
<u>Future developments:</u>

Use the hydrological model outputs to feed the Long-term planning model of the hydropower system (NEWAVE) and see how energy costs will be affected

Uncertainty is problematic. Water mangers will do nothing

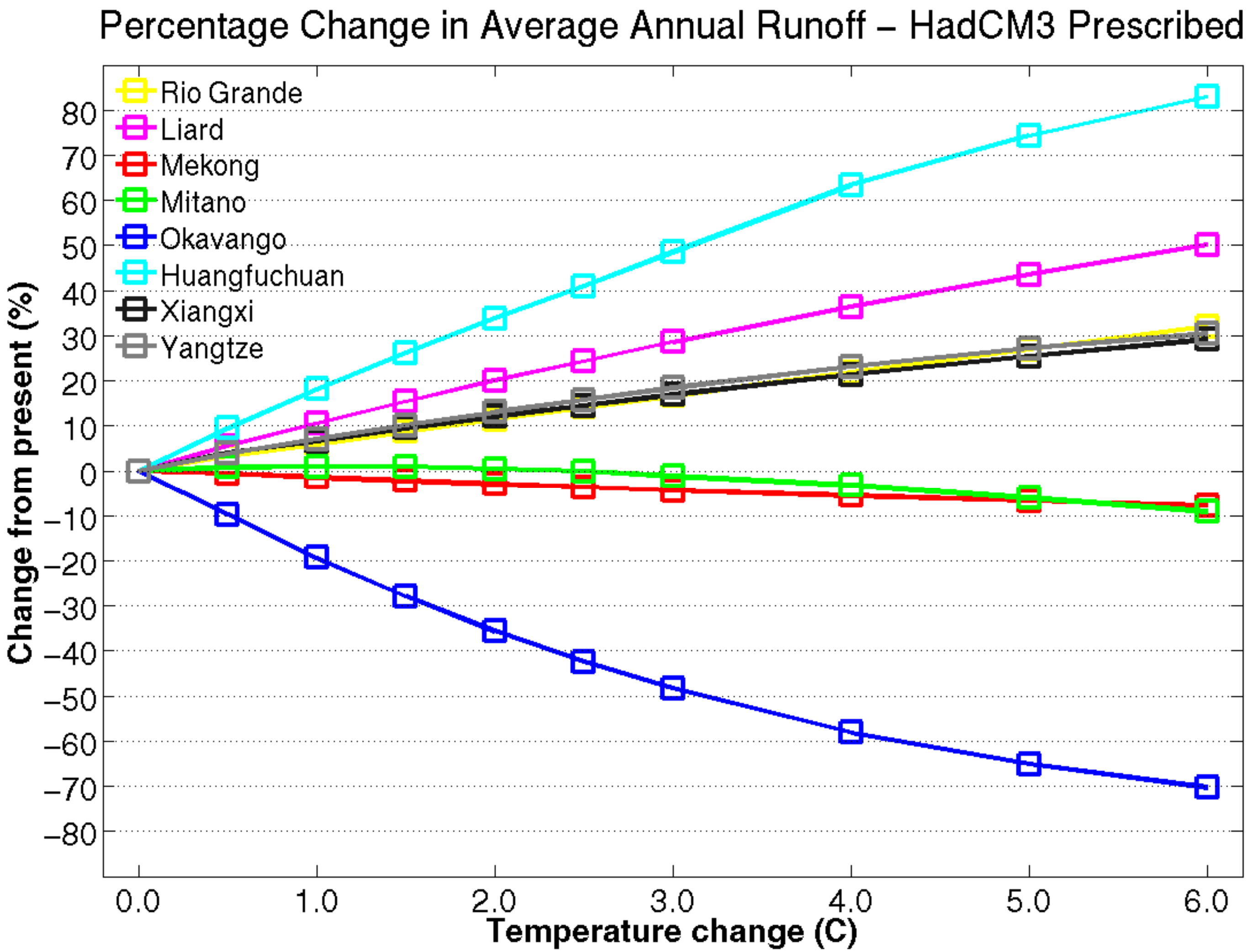
Comparison of catchment and global model results





- **Relative change across GCMs is similar between the global and catchment models**
- **Magnitude of change differs**

Climate impact response function for HadCM3: All basins from global model



Summary of QUEST-GSI

- Integrated global multi-sector climate change impact assessment with consistent climate change scenarios
  - Derive climate impact response functions (as a function of global warming)
- Water resource assessment undertaken with global hydrological model and individual river basin network
- To inform mitigation and adaptation policy

Challenges

1. UNCERTAINTY

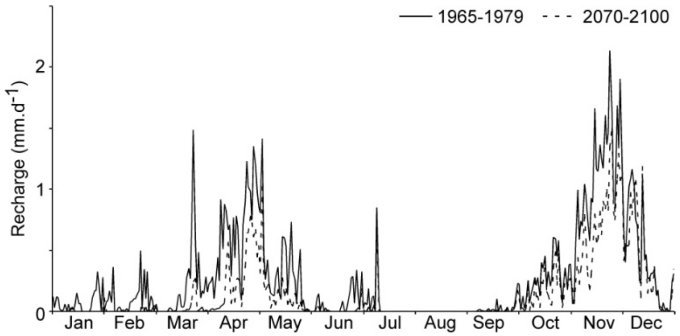
- Very high and probably underestimated
  - Largely associated with GCM precipitation
  - Hydrological model uncertainty of secondary importance
    - Related to Et method?
- Reduce or accept uncertainty?
  - Envelope of non-discountable climate change?
  - Probabilistic estimates from grand ensembles
  - GCM weighting?

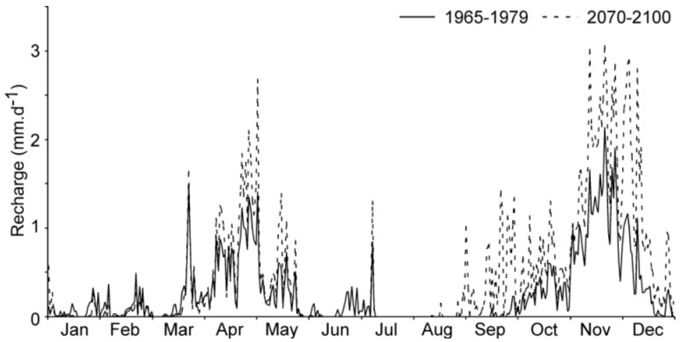
2. ADAPTATION

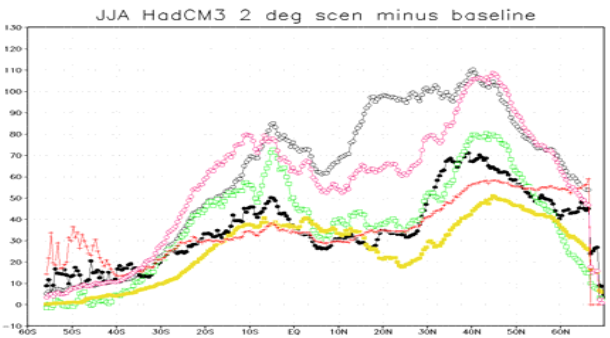
- Adaptive adaptation?
- 'Bottom-up' approach to climate risk assessment and adaptation policy
- Climate is only minor part of adaptation

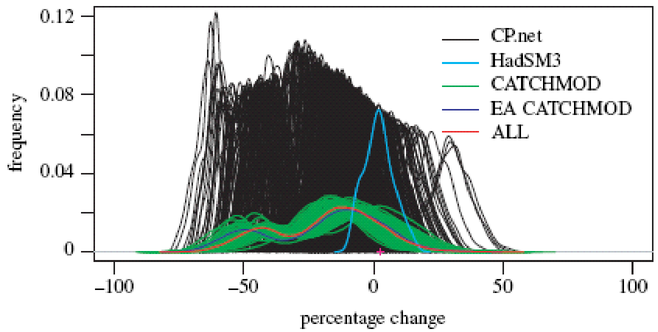
3. WATER STRESS INDICES

- current measures of "water scarcity" do not well inform adaptation
- Need to develop More meaningful water stress indicators (basin by basin)









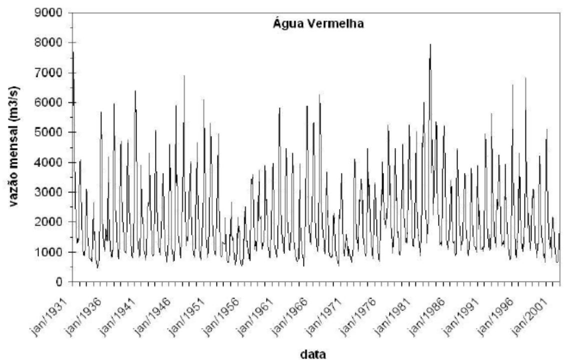


Figura 27 – Vazões médias mensais naturais no Rio Grande em Água Vermelha (área de drenagem total de 138.944 km^2) no período de 1931 a 2001.


Thanks for your attention
Wake up now!