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
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
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
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
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°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: 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

Normalised change 1961-1990 to 2070-2099
Pattern scaling for precipitation
Example

Pattern scaled precipitation signal for ensemble of multiple GCMs

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

Historical timeseries at each global grid cell is perturbed with change in mean and variance from pattern scaled GCM.
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*: \( < 1000 \text{m}^3/\text{capita/year} \)

*“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

![Graph showing the impact of temperature change on millions of people across different regions.](image)
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

Climate Change – Change in Storage Volume (%)

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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- Results
  - Global scale analysis
  - Catchment scale analysis
    - Mekong river
    - Rio Grande
- Conclusions
Catchment-scale studies

Liard (Mackenzie)
McMaster University, Canada

Changjiang (Yangtze)
Changjiang Water Resources Commission

Huangfuchuan (Yellow)
National Climate Centre, China
See presentation of Honmei Xu

Grande (Parana)
Universidade Federal do Rio Grande do Sul, Brazil

Mitano (Nile)
UCL

Okavango
Rhodes University, South Africa, HOORC, University of Botswana
(See my other presentation)

• 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 km², 4200km long, Mean total annual discharge = 475bn m³ (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

- 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

1-6 °C prescribed warming on HadCM3

2 °C prescribed warming across all 7 GCMs

HadCM3 SRES scenarios (2040-2069)

SRES A1b across all 7 GCMs (2040-69)

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

- Tributary 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)

soil water budget and runoff (Arno model),

Calibrated with CRU TS3.0 gridded data
Future developments:

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

Percentage Change in Average Annual Runoff – HadCM3 Prescribed

Change from present (%) vs. Temperature change (°C) for different basins.

- Rio Grande
- Liard
- Mekong
- Mitano
- Okavango
- Huangfuchuan
- Xiangxi
- Yangtze
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)
Thanks for your attention

Wake up now!