Hydrological extremes and feedbacks in the changing water cycle

Contribution from UCL Department of Statistical Science

Christian Onof, impersonating Richard Chandler
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14th February 2011
UCL role in the project

- To provide statistical tools that will translate climate projections to space and time scales appropriate for hydro(geo)logical applications
  - Working closely with Reading group to ensure that statistical tools incorporate physical understanding / mechanisms
  - Providing nonstationary precipitation and evaporation scenarios for use by Imperial and BGS in hydro(geo)logical catchment and land surface modelling
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Personnel:
- Richard Chandler (principal investigator)
- Chiara Ambrosino (researcher, 2-year post)
Climate models getting better but precipitation can still be problematic (depending who you listen to!)

Spatial resolution mostly too coarse for many applications

Expensive to obtain multiple runs for, e.g., uncertainty assessment / accurate estimation of extremes
Statistical downscaling: a way out?

Identify variables that:

- are well reproduced by GCMs / RCMs
- have physically-based relationship with rainfall (laws of physics unlikely to change in altered climate)

**NB:** work at Reading will contribute to this
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- Simulate from statistical model conditioned on GCM / RCM output, to generate synthetic rainfall data at fine scale
Precipitation downscaling in this project

- Using **generalized linear models (GLMs)** with GLIMCLIM software
  ([www.homepages.ucl.ac.uk/~ucakarc/work/glimclim.html](http://www.homepages.ucl.ac.uk/~ucakarc/work/glimclim.html))
- **Tried and tested** methodology
- Provides **multisite, nonstationary, non-Gaussian models for daily precipitation time series**
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- Tried and tested methodology
- Provides multisite, nonstationary, non-Gaussian models for daily precipitation time series
- Nonstationarity controlled by dependence on relevant atmospheric drivers
- Can incorporate changing / seasonally-varying relationships — useful if physics suggests driver effects may change in altered climate
- Models are interpretable: drivers linked to means of probability distributions for daily precipitation

Richard Chandler (richard@stats.ucl.ac.uk)  CWC Steering Group meeting, 14/2/11
Example GLIMCLIM outputs

Distributions of total seasonal rainfall at Heathrow, each from 100 daily GLIMCLIM simulations. Top: JJA, bottom: DJF. Simulations driven by C20 atmospheric sequences (left), HadCM3 outputs 2071–99, A2 scenario (right).
GLIMCLIM: current state

😊 Competitive with other advanced downscaling tools with respect to a wide variety of performance measures including extremes, interannual variability, persistence etc.

😊 Allows simulation at ungauged locations

😊 Allows imputation of missing values conditioned on available observations — hence can quantify uncertainty in historical quantities associated with missing data
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- Allows simulation at ungauged locations
- Allows imputation of missing values conditioned on available observations — hence can quantify uncertainty in historical quantities associated with missing data
- Tends to underestimate extreme summer precipitation event intensities
- Limited options for representing inter-site dependence in precipitation occurrence — designed for catchments up to \( \sim 2000 \text{km}^2 \) but probably inappropriate at larger scales
Precipitation downscaling: deliverables

- Improvements to GLIMCLIM:
  - Improve reproduction of extreme summer precipitation events
  - Provide more flexibility in representing inter-site dependence (in hand — alpha version of software exists)
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- Use models to generate **multiple spatially consistent 1km^2 gridded precipitation / evaporation scenarios** for case study catchments, for input into WP2 and WP3.
Evaporation downscaling

- PE required along with precipitation for hydrological modelling
- Penman formula: PE constructed from wind, air temperature, humidity and radiation
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- Proposal: use statistical downscaling to provide calibrated PE generators as well
- Build on previous experience at UCL and Imperial
- GLM approach here as well (but not GLIMCLIM): generate distributions conditional on large-scale atmospheric structure, then sample required sequences
- Need to ensure mutual consistency between generated PE and precipitation sequences (although previous work suggests dependence is typically weak)
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Prudent management strategies should use information from multiple simulators to acknowledge uncertainty.

Problem: how to combine information to produce something that is relevant to users?

- Large body of literature on this, but arguably little that is ‘decision-relevant’
- Useful to have probabilistic projections that recognise limitations of simulators
- NB simple techniques (e.g. weighting different simulators) cannot address all issues
Illustration: why weighting simulators is silly

- **Toy example**: two GCMs
- **Application**: length of growing season (monthly temp ≥ 12°C)

- GCM 1: reasonable mean temp, hopeless seasonality
- GCM 2: vice versa
- Both underestimate growing season length ⇒ simulator weighting always underestimate
Based on formal representation of how simulators relate to reality:

- Simulators not centred on reality ($\theta_0$) but on reality $+\theta$
- Aim is to use all available data to learn about reality
Features of uncertainty framework

- Works by using all available information to calibrate a statistical emulator of (relevant aspects of) reality
- Transparent, coherent & logically consistent — assumptions are clear so everybody understands perfectly why they disagree (cf heuristic weighting schemes)
- Automatically compensates for all relevant discrepancies between simulator outputs and reality — ‘reward strengths, discount weaknesses’
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- **Transparent, coherent & logically consistent** — assumptions are clear so everybody understands perfectly why they disagree (cf heuristic weighting schemes)
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- ‘**Poor man’s version**’ developed by cutting some statistical corners — little lost in practice, provides **easy and almost instantaneous emulator calibration**
- **Multiple downscaled precipitation / evaporation scenarios will incorporate uncertainty** as represented in this framework
Software

Software environments used at UCL (both open source and free):

- **R**: [www.R-project.org](http://www.R-project.org)
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... and by the way, it’s Chiara’s birthday today …