Statistical and dynamical downscaling of climate model projections

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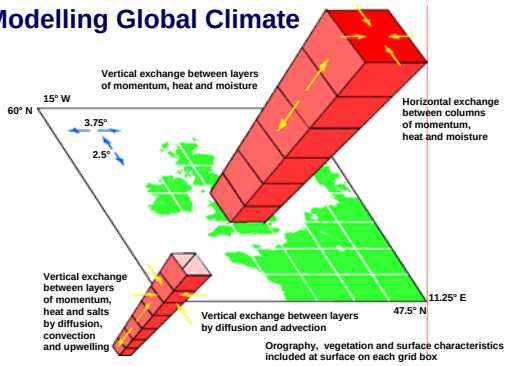
Outline

- The RCM tool
- UKCIP and QUMP ensembles
- GCM -> RCM downscaling

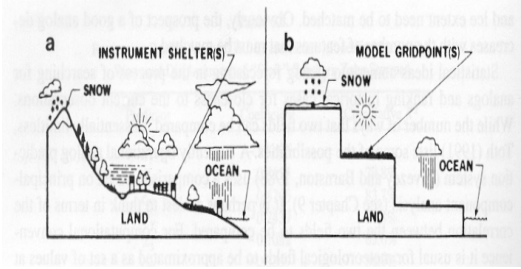
What are regionalization techniques and why are they developed ?

- Impact assessors need regional detail to assess vulnerability and possible adaptation strategies
- AOGCM projections lack that regional detail due to coarse spatial resolution
- Regionalization techniques are developed to allow fine scale information to be derived from GCM output.

Modelling Global Climate



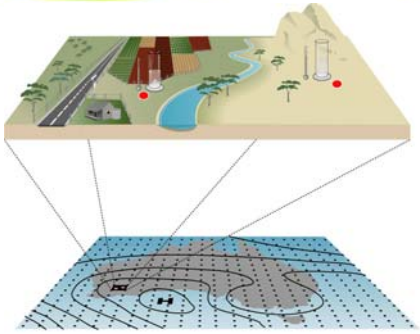
Schematic illustration of the differences between the real world (a) and the world as represented by GCMs (b)



Some key issues in climate modelling

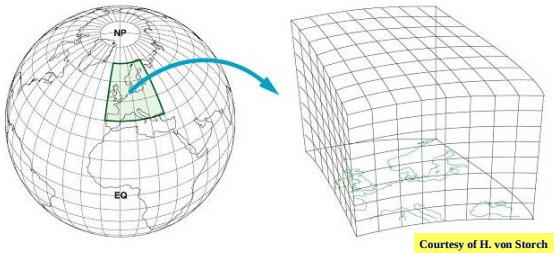
- Representation at finite resolution and timestep
  - grid point and spectral methods
- Solve (integrate) governing differential equations
- *Prognostic* variables
  - take information from timestep to timestep
- Other quantities diagnosed – *diagnostic* variables
- Sub-model coupling or prescribed boundary conditions

From global to local climate ….



… from a GCM grid to the point of

Regional Climate Models (RCM)

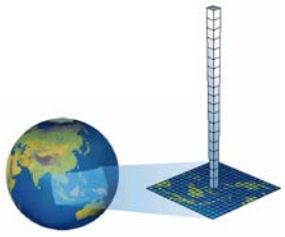


Courtesy of H. von Storch

Regional atmospheric modelling: nesting into a global state

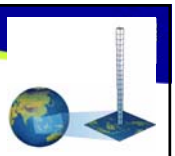
What is a Regional Climate Model?

- Comprehensive physical high resolution climate model that covers a limited area of the globe
- Includes the atmosphere and land surface components of the climate system (at least)
- Contains representations of the important processes within the climate system
  - e.g. clouds, radiation, precipitation, soil hydrology

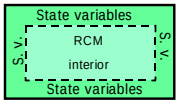


The nesting methodology

- A RCM is a limited area Model (LAM), similar to those used in NWP
- LAMs are driven at the boundaries by GCM or analysis data . . .



Lateral Boundary conditions



- Relaxation method (PRECIS)
  - Large scale forcing over a lateral buffer zone
- Spectral nesting
  - Large scale forcing of low wave number components
- Issues
  - Spatial resolution of driving data
  - Updating frequency of driving data

Sea Surface Boundary conditions

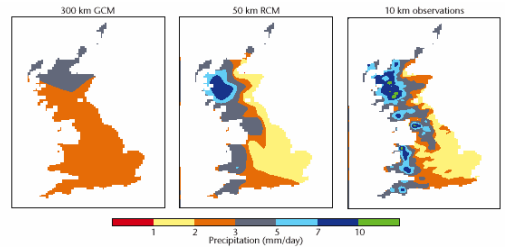
Two methods of supplying SST and ice-extent and thickness:

- Using a coupled AOGCM
  - Need good quality simulation of SST and sea ice in model
- Using observed values
  - For the present-day simulation.
  - For future climate need add to the observed values the changes in SST and ice from a coupled GCM

Sources of errors in RCMs

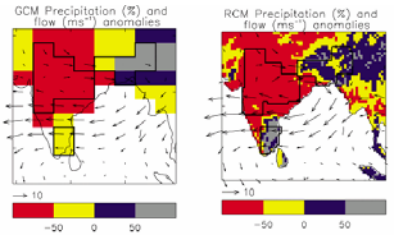
- The RCM adds fine detail to the large-scale and shouldn't deviate from it.
- Two sources of error:
  - Deriving from driving fields
  - Derived from internal model physics.

RCMs simulate current climate more realistically

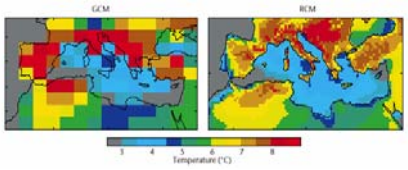


Patterns of present-day winter precipitation over Great Britain

RCMs simulate current climate more realistically

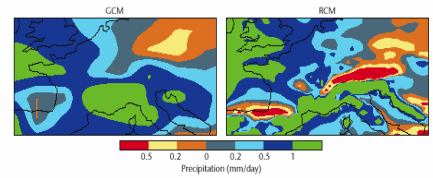


RCMs represent smaller islands



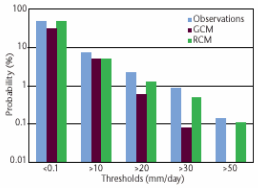
Projected changes in summer surface air temperature between present day and the end of the 21st century.

RCMs predict climate change with more detail



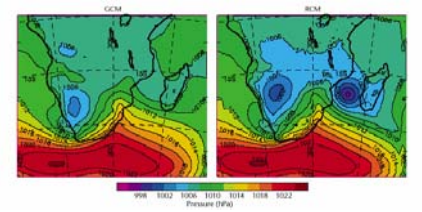
Projected changes in winter precipitation between now and 2080s.

RCMs simulate and predict changes in extremes more realistically



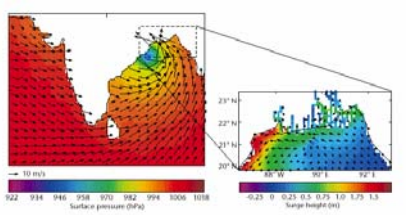
Frequency of winter days over the Alps with different daily rainfall thresholds.

RCMs can simulate cyclones and hurricanes



A tropical cyclone is evident in the RCM (right) but not in the GCM

Data can be used to drive other models



A cyclone in the Bay of Bengal simulated by an RCM and the resulting high water levels in the Bay simulated by a coastal shelf model.

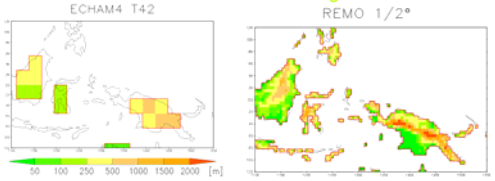
Example of two way nesting

A 10 year simulation using 2-way nesting.
(Lorenz and Jacob, 2005)

Model Orography

Global model ECHAM4 T42

Regional model REMO 1/2°

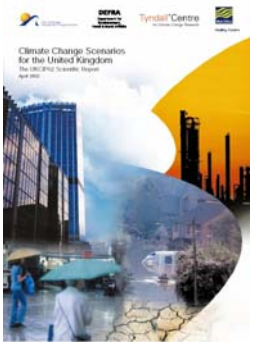


Summary of RCM features

- Main advantage: physically-based ("portable", consistent set of output data, flexible to period and scenario)
- Main disadvantage: computationally expensive, one-way nesting

UKCIP '02

- Based on the state-of-the-art at the time - HadCM3, HadAM3H time-slice, 50km HadRM3 experiments
- Used by many private and public-sector organisations to make decisions and spend money
- "Scenario" based with no quantification of uncertainties (although plenty of caveats pointing this out)

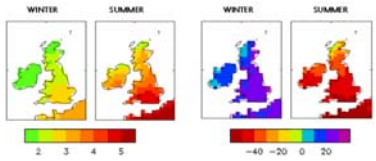


UKCIPnext – Aims and Objectives

- To provide joint probability distribution functions (pdfs) of predicted changes in a selection of key UK climate variables at 25km resolution for each decade during the 21st century
- Results will be presented for each variable by month and summarised as quantiles indicating both mean and extreme outcomes
- The set of climate variables will be determined in consultation with stakeholders
- We aim to deliver the final report and the pdfs during the first half of 2008

Why Ensemble Prediction?

2080 temperature change (K)



2080 precipitation change (%)

We can produce very detailed predictions of climate change with no idea of how reliable they might be

Predicting impacts

Emissions	Scenarios from population, energy, economics models
Concentrations CO_2, methane, sulphates, etc.	Carbon cycle and chemistry models
Global climate change Temperature, rainfall, sea level, etc.	Coupled global climate models
Regional detail Mountain effects, islands, extreme weather, etc.	Regional climate models
Impacts Flooding, food supply, etc.	Impacts models

Probabilities used to Quantify Uncertainties

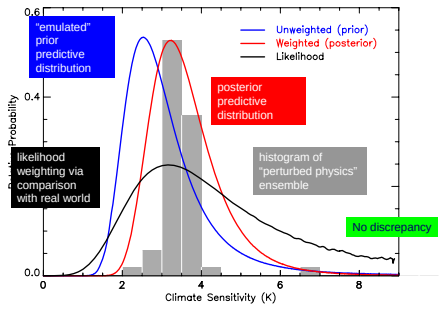
- Future levels of greenhouse gases and other forcing agents (boundary conditions)
- Natural unforced climate variations (initial conditions)
- Uncertainty in representing physical and biological processes in climate models

1. Uncertainties in key parameters in models
2. Uncertainties due to different representations of processes (structural)
3. Omitted processes

Ensemble prediction: Bayesian framework

- Perform a limited ensemble of GCM experiments with perturbed input parameters
- Introduce an *emulator* which can estimate the GCM output at untried parameter values
- Introduce a *discrepancy* term derived from the output of other climate models to represent structural uncertainties
- Produce *prior* predictive distributions of climate variables
- Use observations to produce a *likelihood* function and *posterior* predictive distributions

A simple example



Murphy et al., 2004, Nature, 430, 768-772

QUMP predictions at RCM scale

- 17 RCM 150-years transient simulations at 25km horizontal resolution
- RCMs driven from QUMP GCMs (RCM parameters consistent with GCM)
- Variables from other GCMs will be obtained by statistical downscaling from GCM to RCM scale
- Transferability of methods

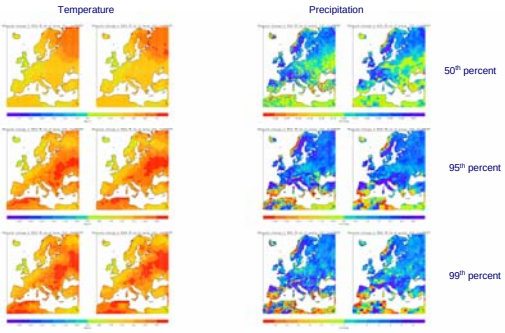
Statistical Downscaling GCM -> RCM

K. Brown (unpublished)

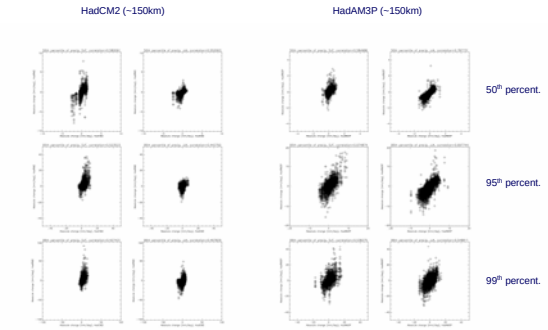
- SDSM (Wilby et al, 2002)
- Daily temperature distribution for UK
- HadAM3P/HadRM3P simulations (1960-1990 and 2070-2100 A2)
- 70% RCM variance explained by GCM temperature
- Preliminary results on precipitation not so good

"Local scaling" approach

E. Kennett (unpublished)



"Local scaling" approach: effect of GCM resolution on precipitation - E. Kennett (unpublished)



Summary

- Additional work required on the GCM -> RCM downscaling for precipitation and extremes for QUMP predictions.
- Simplest method ('local scaling') gives good results for temperature, need to understand if improvements by adding more predictors can be obtained for precipitation

Any Questions?