From raw model output to probabilistic climate projections

Lessons learnt from a Bayesian analysis of regional climate projections in the Alps

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Swiss Climate Scenarios

CH2007 report (coordinated by OcCC)

PRUDENCE

CH2011 report (coordinated by C2SM)

ENSEMBLES

~CH2016 report

CORDEX

~CH2016 or so
Seasonal mean change (T and P) for regions

- West
- North-East
- South

E-OBS Orography [m]
ENSEMBLES GCM-RCM chains

Emission scenario → Global climate models (GCMs) → Regional climate models (RCMs)

- SRES A1B
- HadCM3
  - high sensitivity
  - low sensitivity
- ECHAM5
- ARPEGE
- CGCM3
- IPSL
- HIRHAM (DMI)
- HIRHAM (Met. No)
- RCA (SMHI)
- CCLM (ETH Zurich)
- PROMES (UCLM)
- RRCM (VMGO)
- HadRM3 (Met Office)
- HIRHAM (Met. No)
- RCA3 (C4I)
- HadRM3 (Met Office)
- RCA (SMHI)
- HadRM3 (Met Office)
- REMO (MPI)
- HIRHAM (DMI)
- RACMO (KNMI)
- RCA (SMHI)
- REGCM3 (ICTP)
- ALADIN (CNRM)
- HIRHAM (DMI)
- CRCM (OURANOS)
- CCLM (GKSS)
Goal: Prob. clim. scenarios

Starting point: Model data
Climatology Northern Switzerland (1961-90)

Black: Observations (E-OBS)
Color: ENSEMBLES GCM-RCM chains

- Do systematic biases stay constant with time?
  -> assumed in most published climate projections (e.g. IPCC AR4)
- There is evidence that not! (Christensen et al. 2008, Buser et al. 2009)
  -> potentially large consequences

CH2011: Constant bias assumption
Multimodel projections

Model value  
Switzerland

Quantifying probabilities

[Diagram showing model values and a question mark leading to a probability density function (PDF)]
Goal: Prob. clim. scenarios

Starting point: Model data

Correlations

Bias
ENSEMBLES R2TB

Emission scenario → Global climate models (GCMs) → Regional climate models (RCMs)

- Emission scenario: SRES A1B
- Global climate models (GCMs):
  - HadCM3
    - standard sensitivity
    - high sensitivity
    - low sensitivity
  - ECHAM5
- Regional climate models (RCMs):
  - HIRHAM (DMI)
  - HIRHAM (Md. No.)
  - RCA (SMHI)
  - CCLM (ETH Zurich)
  - PROMES (UCLM)
  - RRCM (VMGO)
  - HadRM3 (Met Office)
  - HIRHAM (Met. No)
  - RCA3 (C4I)
  - HadRM3 (Met Office)
  - RCA (SMHI)
  - HadRM3 (Met Office)
  - REMO (MPI)
  - HIRHAM (DMI)
  - RACMO (KNMI)
  - RCA (SMHI)
  - REGCM3 (ICTP)
  - ALADIN (CNRM)
  - HIRHAM (DMI)
  - CRCM (OURANOS)
  - CCLM (GKSS)
Correlation between GCM-RCM-chains

Temperature Change [K]

- GCM-uncertainty dominates

Average all RCMs driven by the same GCM
Multimodel projections

Model value
Switzerland

Quantifying probabilities

CH2011: Assumption that RCM-averages are independent
Goal: Prob. clim. scenarios

Starting point: Model data

Weights
Correlations
Bias
Effects of weighting

- Increase of error (MSE)
- Decrease of error (MSE)

Benchmark

Model 2 infinitely better than Model 1

Equal weights

Both models have same skill

\[ r = \frac{\sigma_{M2}}{\sigma_{M1}} \]

Effects of weighting

Increase of error (MSE)

Benchmark

Decrease of error (MSE)

Model 2 infinitely better than Model 1

Equal weights

Optimal weights

Both models have same skill

\[ r = \frac{\sigma_{M2}}{\sigma_{M1}} \]

Effects of weighting

- Increase of error (MSE)
- Benchmark
- Decrease of error (MSE)

- Worst possible weights
- Optimal weights
- Equal weights

$r = \frac{\sigma_{M2}}{\sigma_{M1}}$

Model 2 infinitely better than Model 1

Both models have same skill

Effects of weighting

- Increase of error (MSE)
  - Benchmark
  - Equal weights
  - Optimal weights
  - Random weights

- Decrease of error (MSE)
  - Model 2 infinitely better than Model 1
  - Both models have same skill

$\rho = \frac{\sigma_{M2}}{\sigma_{M1}}$

CH2011: No skill-based weights

Goal: Prob. clim. scenarios
Starting point: Model data
Statistical model
Weights
Correlations
Bias
Multimodel projections

Model value
Switzerland

Quantifying probabilities

CH2011: Bayesian algorithm of Buser et al. (2009)
Bayesian model of Buser et al. (2009)

Observations CONTROL \sim N(\mu,...)
Models CONTROL \sim N(\mu + \beta_i,...)
Observations FUTURE \sim N(\mu + \Delta\mu,...)
Models FUTURE \sim N(\mu + \Delta\mu + \beta_i + \Delta\beta_i,...)

\mu: Climate mean during control period
\beta_i: Systematic bias of model i
\Delta\mu: Climate change signal
\Delta\beta_i: Projection error of model i
Goal: Prob. clim. scenarios

Starting point: Model data

Prior of model error

Statistical model

Weights

Correlations

Bias
Multimodel projections

Model value
Switzerland

Quantifying probabilities

\( \sigma^2 \Delta \beta_i \)

CH2011: ENSEMBLES model chains fully sample model uncertainty
CORDEX-Meeting Trieste | 21-24 March 2011
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Goal: Prob. clim. scenarios

Starting point: Model data

Natural variability

Prior of model error

Statistical model

Weights

Correlations

Bias
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Model value
Switzerland

Quantifying probabilities

Discrepancies not only due to model error, but also due to internal decadal variability

Approach:
1. Filter out internal variability (Hawkins and Sutton 2009)
2. Bayesian model combination
3. Re-add internal variability
Swiss Climate Scenario (A1B)

**Temperature (K)**

- 2035 - 1995
- 2060 - 1995
- 2085 - 1995

**Precipitation (%)**

- Chains averaged according to GCM
- Individual GCM-RCM chains

Goal: Prob. clim. scenarios

Starting point: Model data

Natural variability

Prior of model error

Statistical model

Weights

Correlations

Bias
CH2011:

“Projection intervals should be interpreted as possible ranges of future climate evolution, which are consistent with the data at hand but may change as more information become available and more sources of uncertainty are included.“

Goal: Prob. clim. scenarios

Natural variability

Prior of model error

Statistical model

Weights

Correlations

Bias

Starting point: Model data