Uncertainties in multi-model climate projections

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Climate Change impact studies

• we need: weather data representing future climate to be used as an input to our model (crop model, rainfall-runoff model, …)

• we have: (numerous) GCM simulations for several emission scenarios (typically: SRES-A2, -A1b, -B2, -B1)
Our aim in climate change impact studies: probabilistic assessment reflecting existing uncertainties (…at least some of them)

For this, we need scenarios from

Several emission scenarios X several GCM simulations

(GCMs: various models, various settings, various realisations)

• ... but: GCM simulations need huge computer resources
  - >> only limited number of GCM simulations available
  - >> GCM simulations do not cover existing uncertainties in emissions, climate sensitivity)

• so, to account for the uncertainties, we may use:
  – http://www.climateteprediction.net
  – pattern scaling, which separates global and regional uncertainties
www.climateprediction.net:
$\Delta T_{G,2xCO_2}$ (=climate sensitivity; $K$ =)

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**IPCC-AR4 GCMs: $T_{glob}$ at SRES-A2:**
11 GCMs (colour time series) vs MAGICC model run at various climate sensitivities; yellow bar on the right)

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The range of $\Delta T_{glob}$ simulated by a set of GCMs is not representative for the uncertainty in climate sensitivity → “pattern scaling” method may help.
pattern scaling technique

**assumption**: pattern (spatial and temporal /annual cycle/) is constant, only magnitude changes proportionally to the change in global mean temperature:

\[ \Delta X(t) = \Delta X_S \times \Delta T_G(t) \]

where \( \Delta X_S = \text{standardised scenario (related to } \Delta T_G = 1^\circ C) \)

a) \( \Delta X_S = \Delta X_{[tA-tB]} / \Delta T_G [tA-tB] \)

b) linear regression \([x = \Delta T_G; y = \Delta X]\)

\( \Delta T_G = \text{change in global mean temperature} \)

!! may be estimated by other means than GCMs (e.g. simple climate model MAGICC)

"validity" of pattern scaling

- TEMP : well correlated with \( T_{GLOB} \)
- PREC, DTR, SRAD, VAPO, WIND: low correlation with \( T_{GLOB} \)
  - natural variability dominates?
  - ..... this may be simulated by WG

- be careful with extrapolation!
  (don’t scale with too large \( \Delta T_{globe} \))

Variance of grid-specific TEMP and PREC changes explained by the pattern scaling technique (RV) (averaged over 12 monthly values)
present experiments

- **data**: 14 GCMs (IPCC - AR4 database) run at SRES-A2 and SRES-A1b

- **outputs**:
  - **GCM validation**: GCM vs. CRU (1961-1990)
  - **climate change scenarios**
  - “validity” of pattern scaling: \( RV(T_{AVG}, T_{glob}) \), \( RV(PREC, T_{glob}) \)
  - A2 vs A1b

  - **multi-GCM maps**: the results presented in maps showing both median from 14 GCMs and between-GCM variability

GCMs used in the analysis

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Annual cycle of the GCM-based 1961-90 monthly means
1. regridded into the CRU’s 0.5×0.5° grid)
2. compared with CRU gridded climatological monthly means (TS2.1 dataset)

temperature is validated in terms of: BIAS, RV, RMSE
precipitation is validated in terms of: %BIAS, RV, %RMSE

where:

BIAS = avg(GCM) – avg(CRU) (*)
%BIAS = 100 × BIAS / avg(GCM) (*)
RV = Reduction in Variance (Y=CRU m.means; Y^= debiased GCM m.means)
RMSE = Root Mean Square Error (debiased GCM m.means vs CRU m.means)
%RMSE = 100 × RMSE / avg(GCM) (*)

(*) avg(X) is an average of 12 monthly values (in validation of the annual cycle)
GCMs vs CRU (1961-90 monthly means)

RMSE(annual cycle of TAVG)

GCMs vs CRU (1961-90 monthly means)

RV(annual cycle of TAVG)
GCMs vs CRU (1961-90 monthly means)

RMSE(annual cycle of PREC)

GCMs vs CRU (1961-90 monthly means)

RV(annual cycle of PREC)
motivation: to show the multi-model mean/median + uncertainty in a single map

**step1:** results obtained with each of 7 GCMs are re-gridded into 0.5x0.5° grid (~CRU data)

**step2:** median \[\text{med}(X)\] and std \[\text{std}(X)\] from the 18/14 values in each grid box are derived

**step3 (map):** the median is represented by a colour, the shape of the symbol represents value of uncertainty factor \(Q\):

\[
Q = \frac{\text{std}(X)}{\text{med}(X)}
\]

interpreting the uncertainty:
- squares and circles \[\text{std}(X) \leq 0.5 \times \text{median}(X)\] indicate that \text{med}(X) differs from 0 at significance level higher than 95% (roughly)
- 4-point stars indicate high uncertainty \[\text{std}(X) > \text{med}(X)\]

or: the greater is the proportion of grey (over sea) or black (over land) colour, the lower is the significance, with which the median value differs from 0

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**Multi-GCM Validation: annual cycle (TAVG)**

(median [~colour] and STD [~symbol] of 18 single-GCM values)

- bias mostly relates to misreproduction of orography in GCMs

BIAS = GCM - CRU
Multi-GCM Validation: annual cycle (TAVG)

(median [~colour] and STD [~symbol] of 18 single-GCM values)

\[ \text{RMSE}^* = \sqrt{\text{avg} (GCM_i - CRU_i - \text{bias})^2} \]

- BLUE / RED indicates low / high RMSE
- large / small symbols represent high / low between-GCM concordance

\[ \text{RV}^* = 1 - \frac{\text{RMSE}^2}{\text{RMSE}_0^2}; \text{ where } \text{RMSE}_0 = \sqrt{\text{avg} \{GCM_i - \text{avg} (GCM_i) \}^2} \]

RV close to 1 indicates perfect correlation between TAVG and \( T_{\text{globe}} \)
Multi-GCM Validation: annual cycle (PREC)

(median [~colour] and STD [~symbol] of 18 single-GCM values)

%BIAS = (GCM – CRU) / CRU

- high bias in the mountains and close the shores

%RMSE* = 100 * sqrt [ avg (GCM_i – CRU_i – bias)^2 ] / avg(CRU)

- note the areas with good GCM performance (BLUE) and high between-GCM concordance
Multi-GCM Validation: annual cycle (PREC)

(median [~colour] and STD [~symbol] of 18 single-GCM values)

\[ RV^* = 1 - \frac{RMSE^2}{RMSE_0^2}; \text{ where } RMSE_0 = \sqrt{\text{avg} \left( GCM_i - \text{avg} \left( GCM_i \right) \right)^2} \]

- low correlation with CRU may be partly due to insignificant annual cycle of PREC

Summary: Multi-GCM Validation of annual cycle: (18 GCMs)

- not that annual cycle of PREC is reproduced much worse by GCMs
multiGCM scenarios (standardised)
(14 GCMs, SRES-A2)

- TAVG, PREC (SRES-A2)
- correlation between TAVG and PREC with $T_{globe}$
- SRES-A2 vs SRES-A1b

14-GCM standardised scenario – $\Delta$TAVG (SRES-A2)

nearly whole Europe: $\text{STD}(\Delta T) < 0.4 \times \text{median}(\Delta T)$
14-GCM standardised scenario – $\Delta$PREC (SRES-A2)

- Spring
- Summer
- Autumn
- Winter

$\Delta$TAVG

1-RV(TAVG,Tglobe)

std. scenario - TAVG (14 GCMs, SRES-A2)

!!! STD > 2*median !!!
• low between-GCM fit ~ low PREC-TAVG\textsubscript{glob} correlation
  low climate change signal \(\rightarrow\) natural climate variability dominates and manifests itself as a stochastic noise \(\rightarrow\) between-GCM differences

• high between-GCM fit ~ high climate change signal

• not found on the present maps:
  - low between-GCM fit + high climate change signal (if found, it would indicate contradictions between GCMs; … maybe the case of summer temperature changes)
  - good between-GCM fit + low climate change signal
    / would be an “extreme” stochastic event
SRES-A2 vs SRES-A1b

IPCC-AR4 GCMs: $T_{glob}$ at SRES-A2/A1b

![Graph showing temperature changes for SRES-A2 and SRES-A1b simulations using IPCC-AR4 GCMs.](image)
SRES-A2 vs A1b: \( \Delta \text{TAVG} \)

SRES-A2 - SRES-A1b:
- Spring
- Summer
- Autumn
- Winter
- Year

1-RV(TAVG, Tglobe) - SRES-A2

1-RV(TAVG, Tglobe) - SRES-A1b
SRES-A2 vs A1b: ΔPREC

STD > 2*median

1-RV(PREC, Tglobe) – SRES-A1b

SRES-A2 vs A1b: 1-RV(PREC, TAVGglobe)

- spring
- summer
- autumn
- winter
1) validation of the annual cycle

- **GCMs** better fit **TEMP** then **PREC**
  - **TEMP**: good performance + good between-GCM fit in Central+W.Europe, incl. UK
  - **PREC**: good performance + good between GCM concordance in:
    - west. UK
    - Norway+Finland
    - Portugal
    + parts of the Mediterranean
- **RV** & **RMSE** provide different patterns

2) standardised scenario:

- **TAVG** perfectly correlated with **T_globe**
- **PREC**: lower correlation with **T_globe**
  - regional & seasonal patterns
  - lowest correlation along 50th parallel
  - low correlations with **T_globe** (and large between-GCM differences) are assumed to be due to low climate change signal (natural climate variability dominates)

**be careful with extrapolation!**

*(don’t scale std. scenarios with large ΔT_globe)*
3) CC scenario for Europe:

- **TAVG** increases everywhere during the whole year; largest increases in S.Eu. (summer) and NE Eu. (autumn)

- **PREC**: decreasing in South and increasing towards North (note the nice zonal pattern in changes in annual PREC)

- Mediterranean: significant PREC decrease in in spring and summer → drought risks will increase

- North: increased temperature is accompanied by PREC increase

- SRES-A2 vs SRES-A1b: little differences between standardised scenarios
Thanks for your attention!