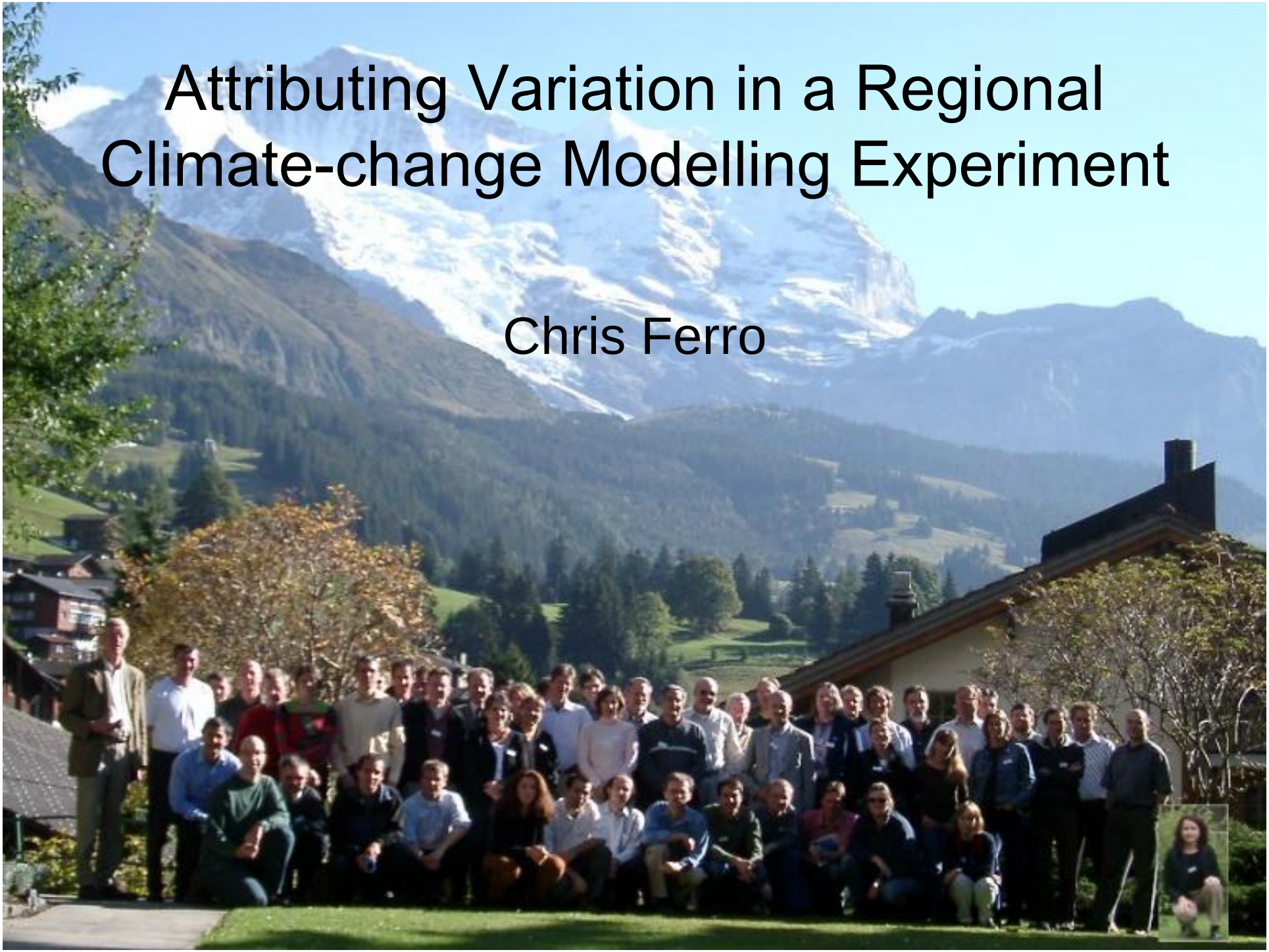
Attributing Variation in a Regional Climate-change Modelling Experiment

Chris Ferro



The PRUDENCE Project

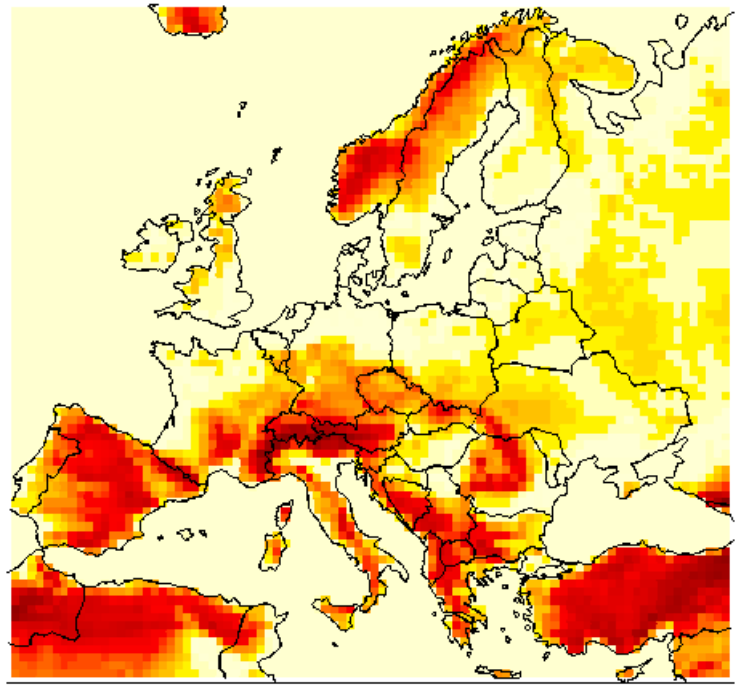
European climate simulations

9 limited-area RCMs, driven by various global GCMs

Control 1961–1990

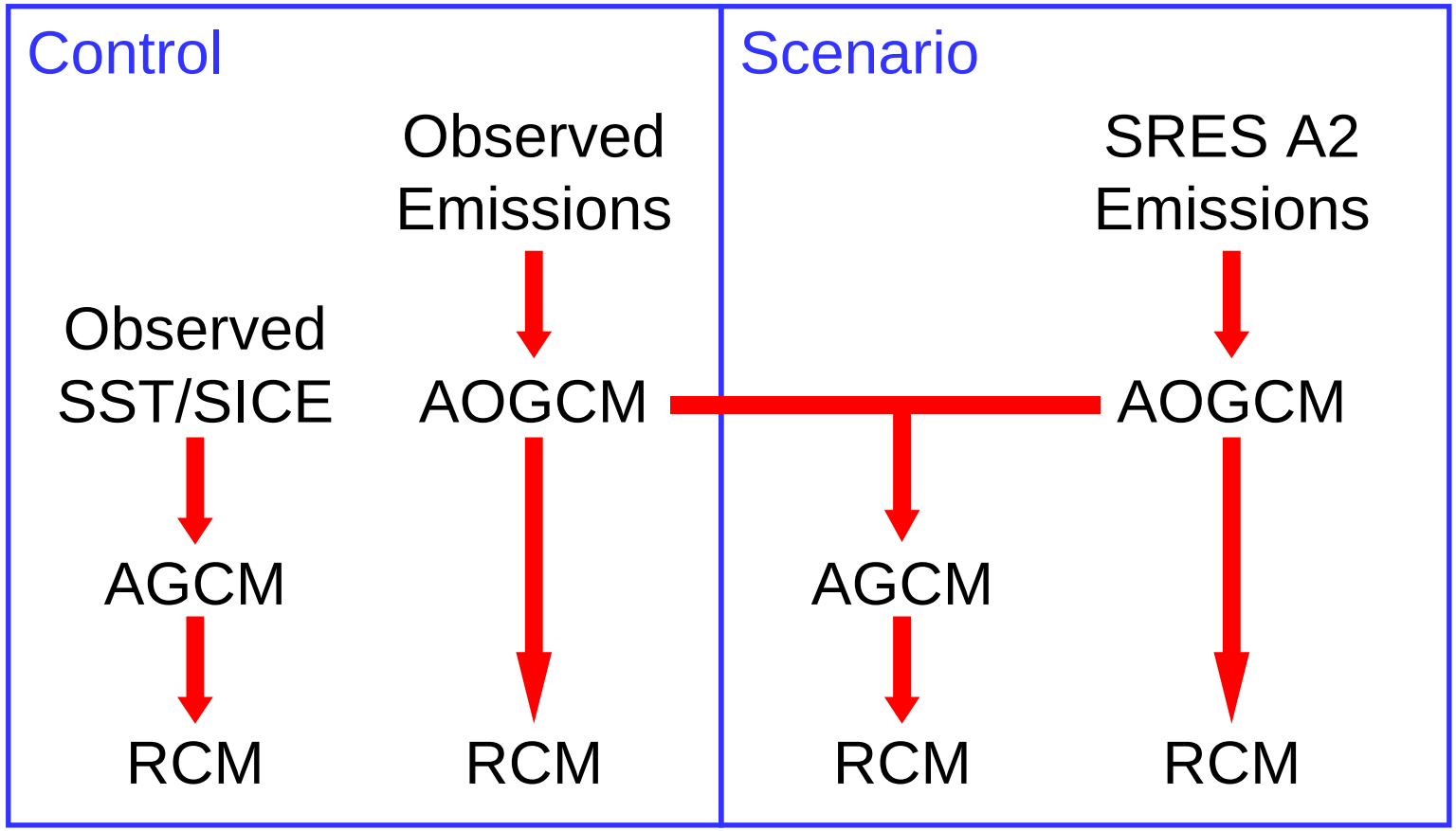
Scenarios 2071–2100

http://prudence.dmi.dk



Orography at 50km resolution

Experimental Design



Aims

Characterise

projected climate change

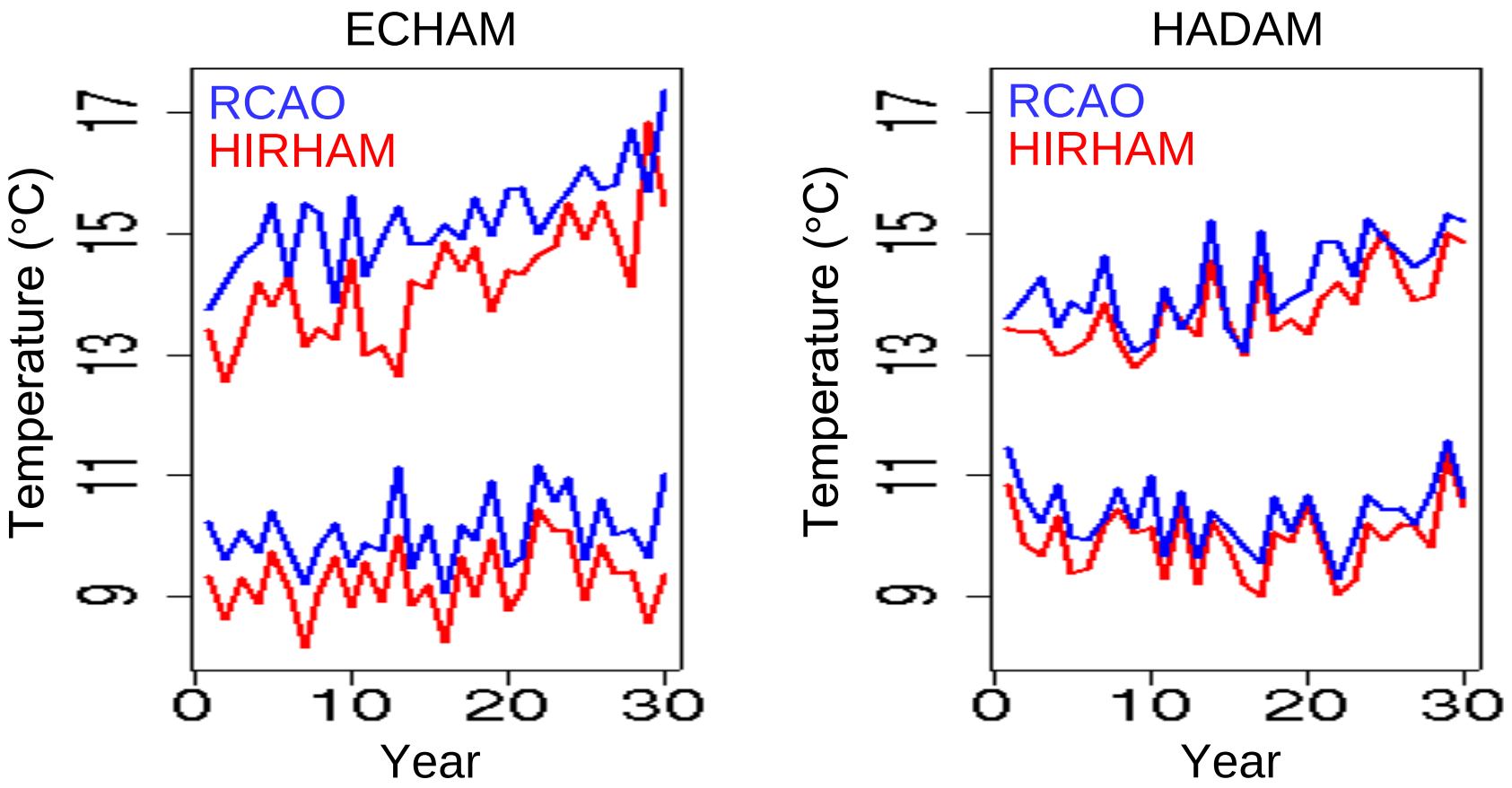
effects of model differences

relative importance of different model components: emissions, GCM, RCM and initial conditions

Selected Experiments

	HADCM3 / HADAM3H		OPYC3 / ECHAM4		
RCM	C	A	C	A	Group
CHRM	1	1			ETHZ
CLM	1	1			GKSS
HADRM	1	1			HC
HIRHAM	1	1	1	1	DMI
PROMES	1	1			UCM
RACMO	1	1			KNMI
RCAO	1	1	1	1	SMHI
REGCM	1	1			ICTP
REMO	1	1			MPI

Land-averaged annual mean 2m air temperature interpolated to CRU grid



General Linear Model

$T_{i\,j\,k\,l}$ is temperature for GCM i, RCM j, Period k, Year l

$$T_{i\,j\,k\,l} = \alpha_{i\,j\,k} + \beta_{i\,j\,k}\, t_l + \gamma_{i\,j\,k}\, t_l^2 + Z_{i\,j\,k\,l}$$

Residuals $Z_{i\,j\,k\,l} \sim N(0, \sigma^2_{i\,j\,k})$, $\mathrm{cor}(Z_{i\,j\,k\,l}, Z_{i\,j'\,k\,l}) = \rho_{i\,k}(j, j')$

$$\alpha_{i\,j\,k} = \alpha + \alpha_i^G + \alpha_j^R + \alpha_k^P + \alpha_{i\,j}^{GR} + \alpha_{i\,k}^{GP} + \alpha_{j\,k}^{RP} + \alpha_{i\,j\,k}^{GRP}$$

Similarly for $\beta_{i\,j\,k}$ and $\gamma_{i\,j\,k}$ with constraints for uniqueness

Simplified Model

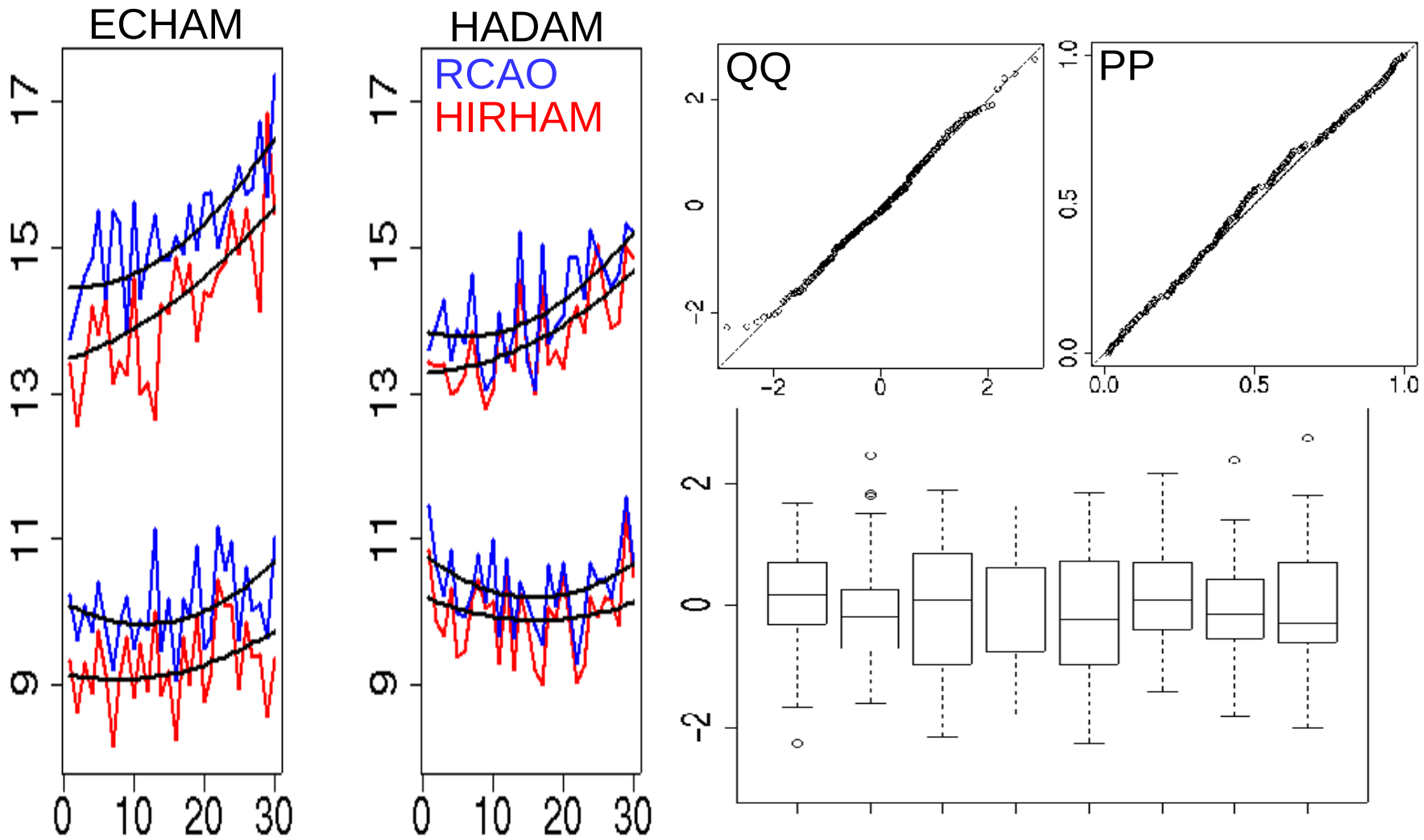
$$T_{i\,j\,k\,l} = \alpha + \alpha_i^{G} + \alpha_j^{R} + \alpha_k^{P} + \alpha_{i\,j}^{GR} + \alpha_{i\,k}^{GP} + (\beta + \beta_i^{G} + \beta_j^{R} + \beta_k^{P})\, t_l + (\gamma + \gamma_j^{R})\, t_l^{2} + Z_{i\,j\,k\,l}$$

α	12.1 (0.03)	β	-0.3 (0.15)
α_1^{G}	0.07 (0.04)	β_1^{G}	0.10 (0.04)
α_1^{R}	-0.33 (0.01)	β_1^{R}	0.11 (0.05)
α_1^{P}	-2.22 (0.04)	β_1^{P}	-0.26 (0.04)
α_{11}^{GR}	-0.13 (0.02)	γ	0.21 (0.05)
α_{11}^{GP}	-0.31 (0.05)	γ_1^{R}	-0.03 (0.02)

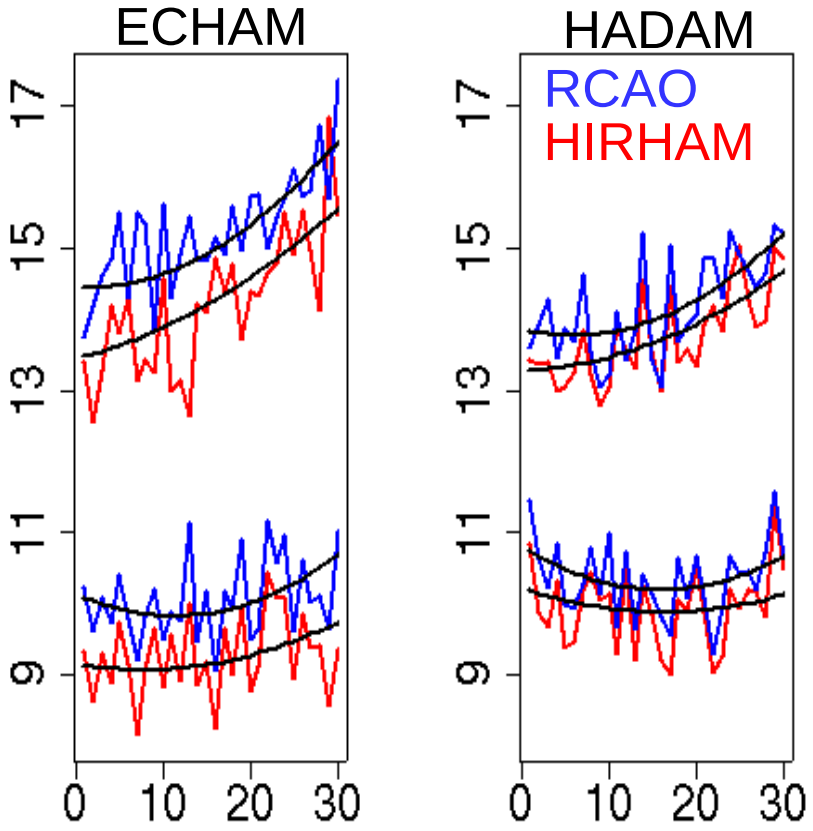
$\sigma_{i\,j\,k}$	C	A
HIRHAM-E	0.56	0.62
RCAO-E	0.55	0.51
HIRHAM-H	0.50	0.43
RCAO-H	0.46	0.52

$\rho_{i\,k}$	C	A
ECHAM	0.92	-0.10
HADAM	0.88	0.82

Diagnostic Plots

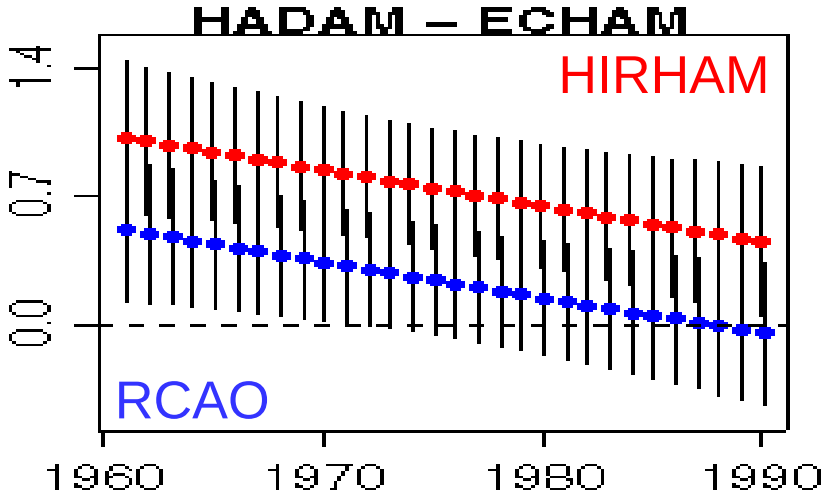


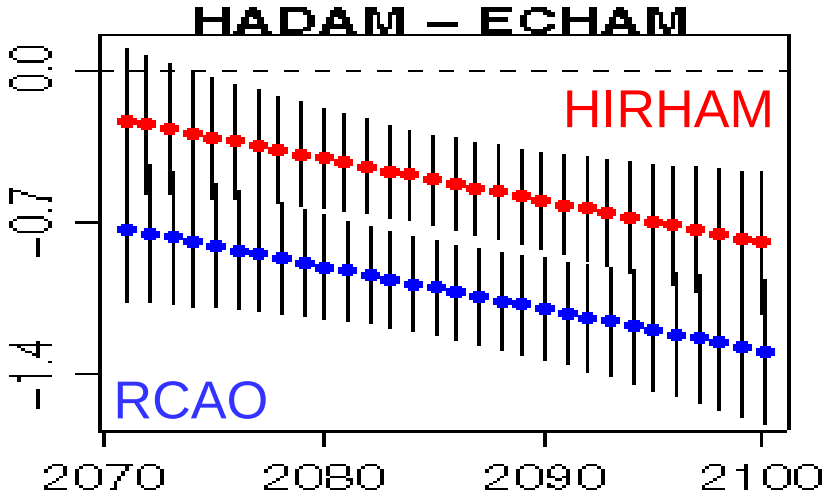
Variance Partition

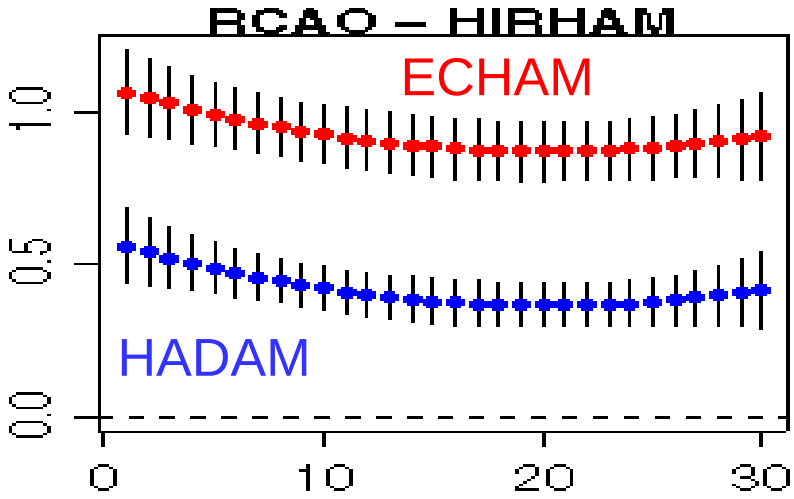


	%
Trend	91.0
GCM	0.1
RCM	2.0
G x T	1.8
R x T	0.0
G x R	0.3
G x R x T	–
Z	4.7

Temperature Contrasts (°C)



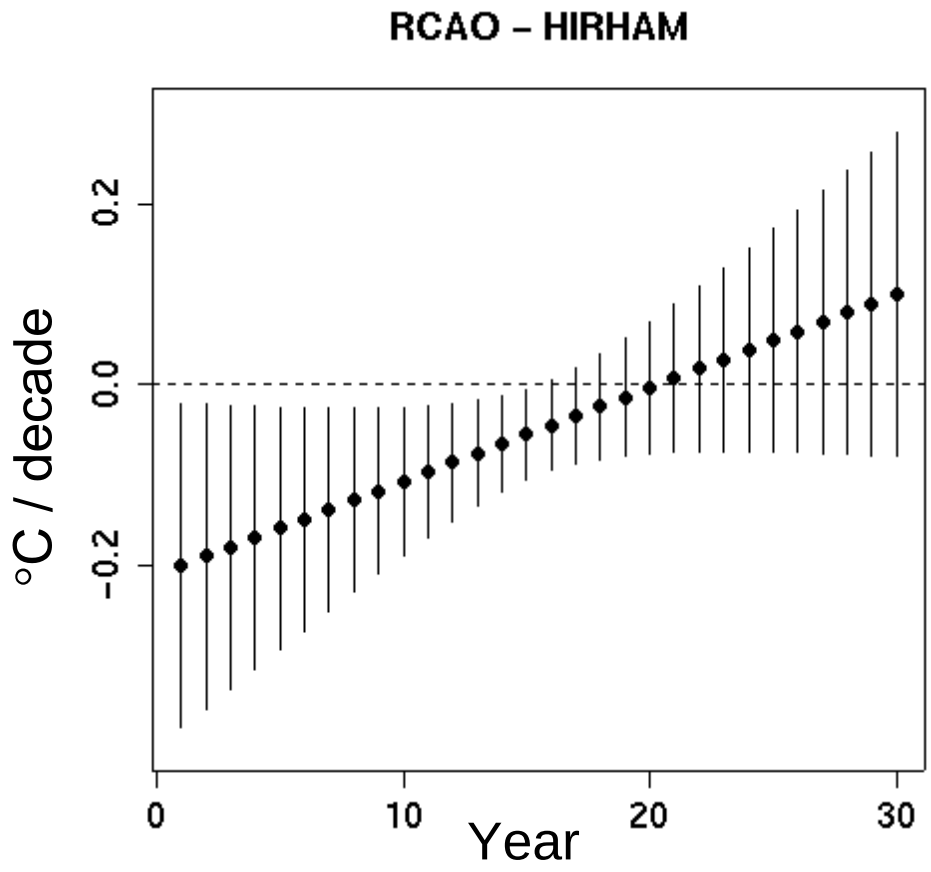




HADAM warmer than ECHAM at 1961 becomes progressively cooler – warm bias greater for HIRHAM

RCAO warmer than HIRHAM – warm bias greater for ECHAM

Response Contrasts



HADAM – ECHAM response
-0.19°C/decade (-0.37, -0.02)

HADAM response lower than ECHAM independently of RCM, Period, Year

RCAO response lower than HIRHAM at start of integration, becomes progressively higher independently of Period, GCM

Grid-point Analysis

Fit model separately at each grid point and plot maps:

Proportion of variation explained by each model term

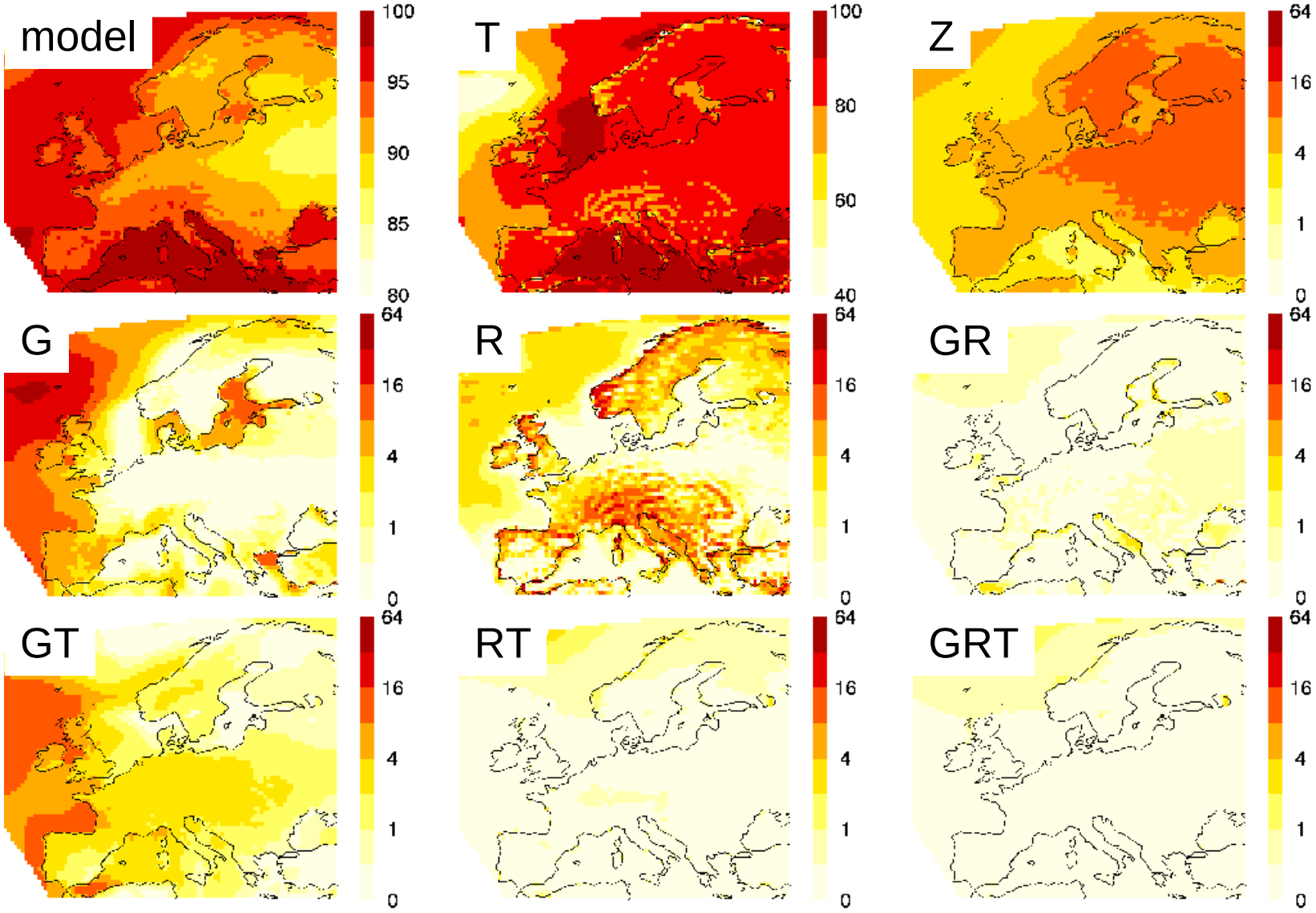
Evolution of GCM temperature contrasts for each RCM

Evolution of RCM temperature contrasts for each GCM

Evolution of GCM response contrasts for each RCM

Evolution of RCM response contrasts for each GCM

Variation Explained (%)



Review

Method: statistical model synthesises output and enables inference on climate changes, model differences, and the relative importance of model components.

Results: warming signal dominates, choice of RCM affects temperature in mountainous regions, choice of GCM affects temperature and response in Atlantic and response over land, inter-annual variation is greater than GCM and RCM effects over land, effects of model differences change over space and time.

Extensions: variables (EOFs), annual cycle, model resolution

Lessons

Extracting complex details is challenging but worthwhile

Danger of over-simplified summaries of model output

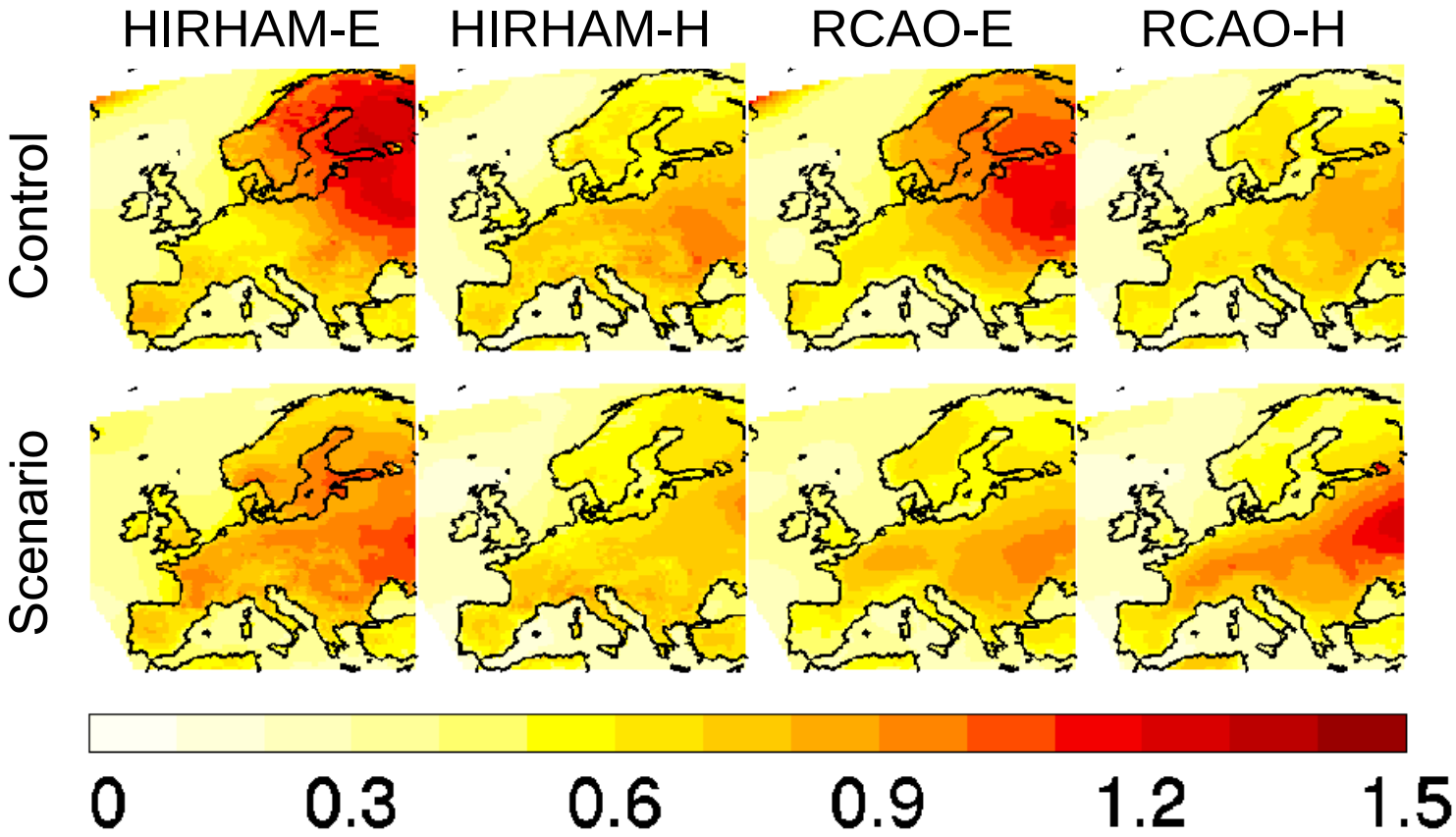
Features can be hidden by poor experimental design

Minor experiment details can be important for analysis

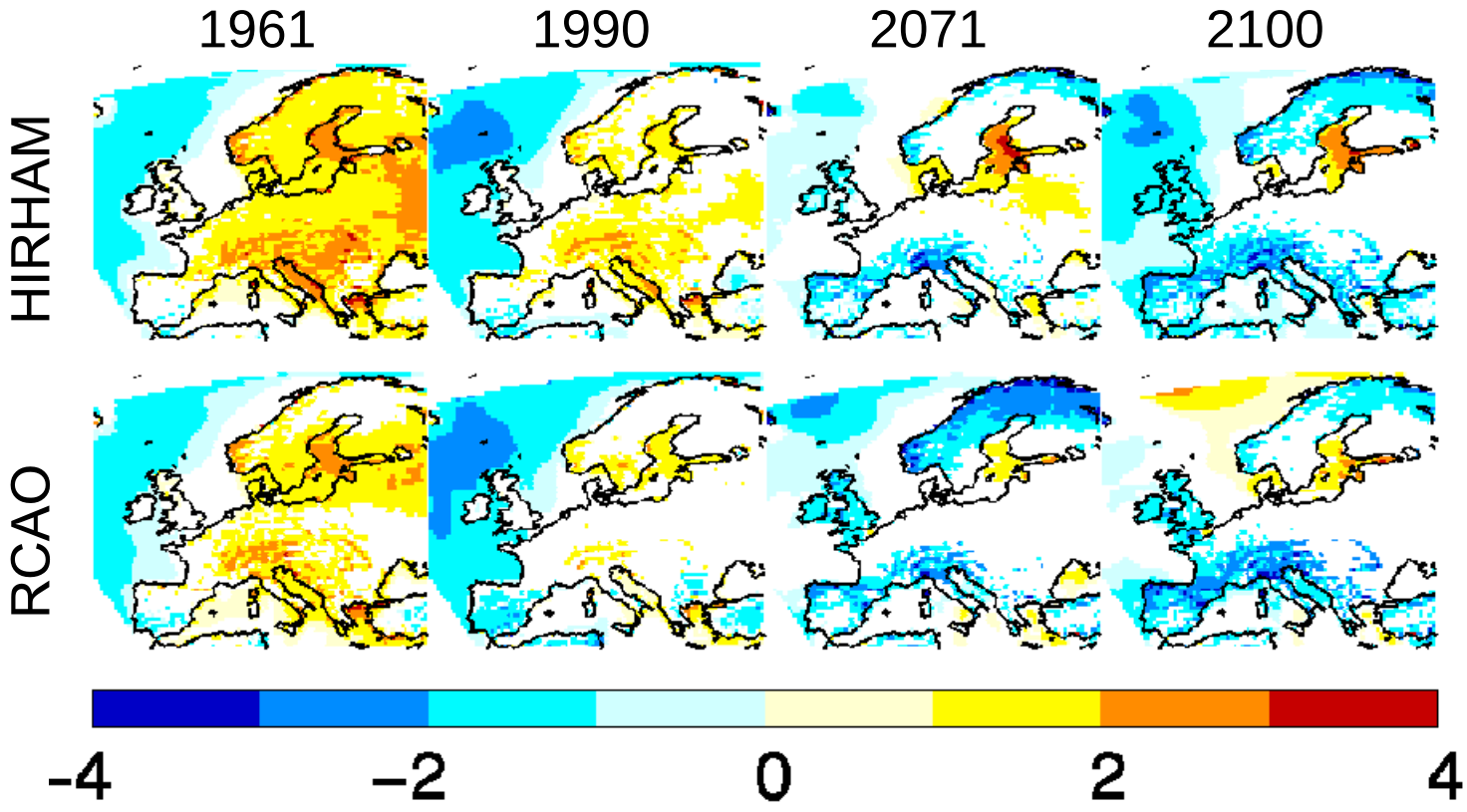
Huge literature on experimental design and analysis

Design experiments carefully with view to analysis!

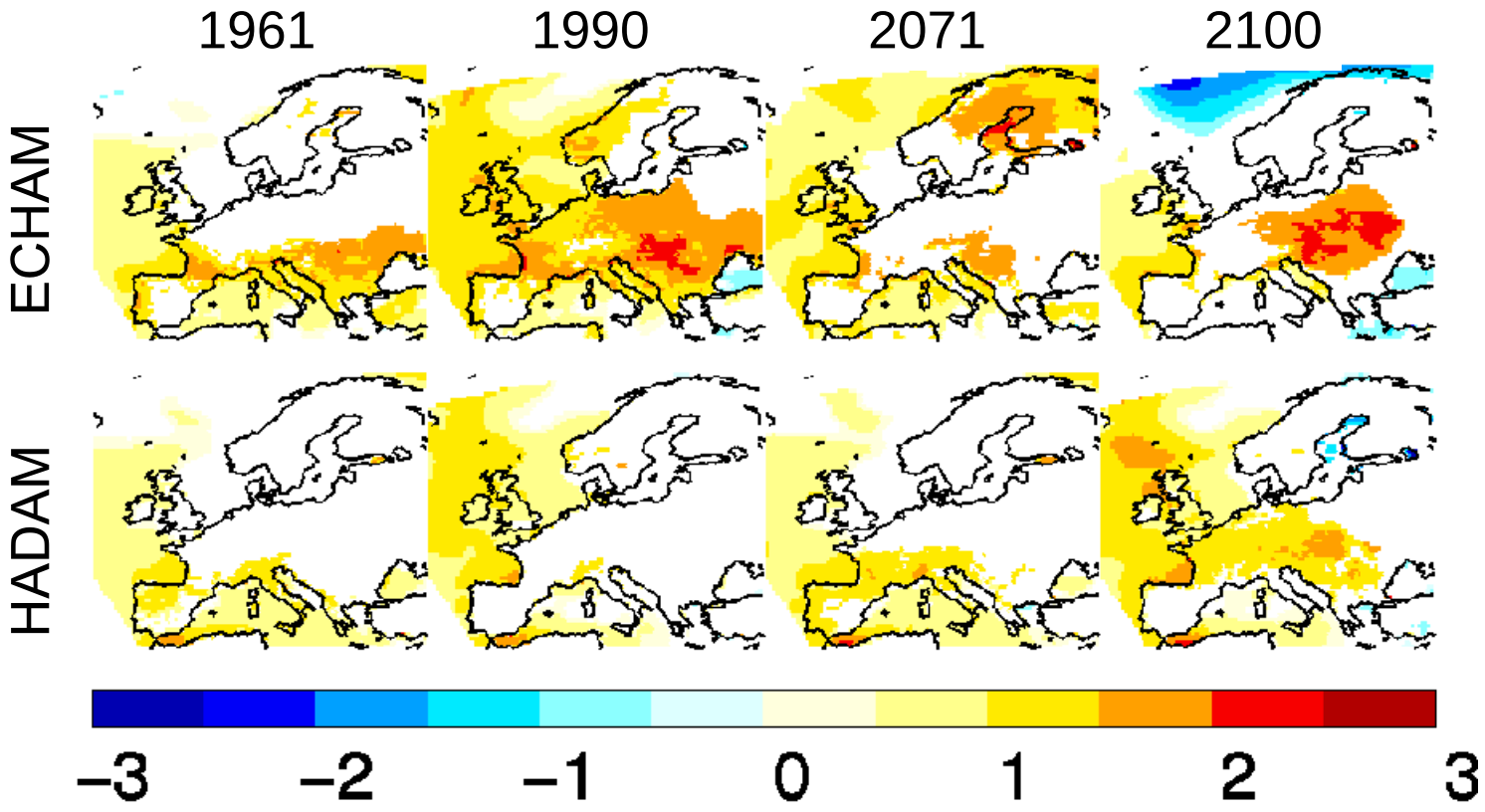
Residual Standard Deviation (ºC)



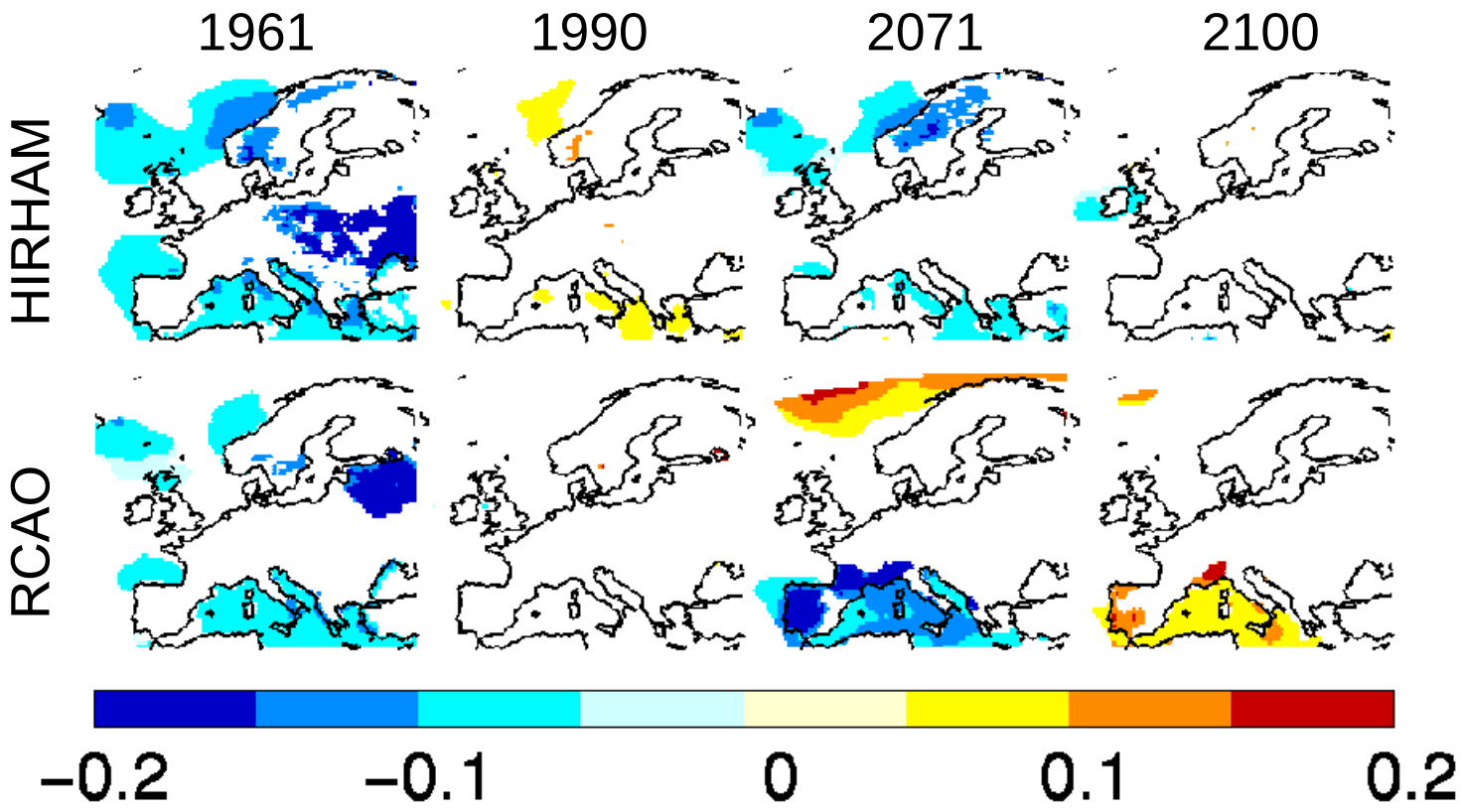
Temperature Contrasts: HADAM – ECHAM



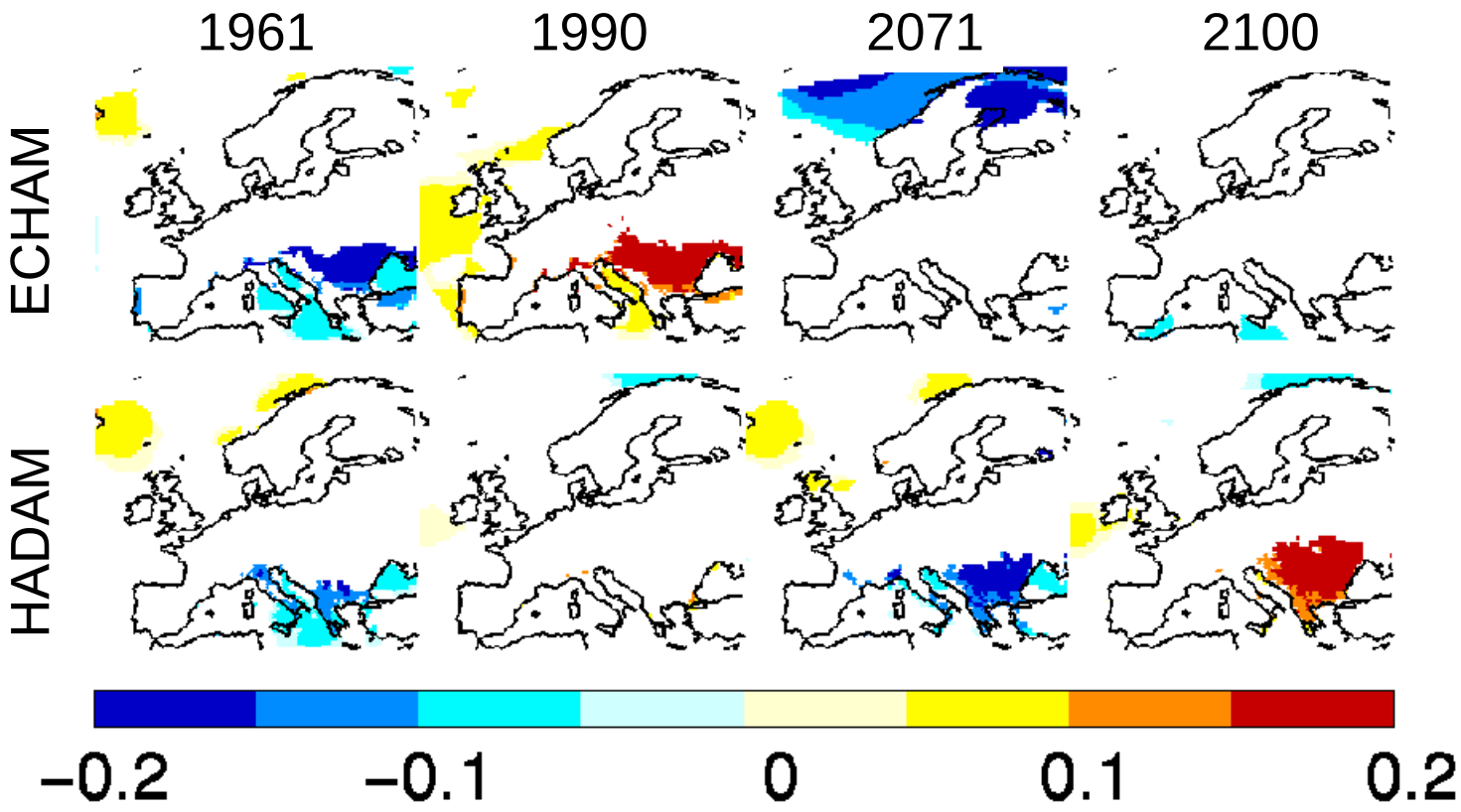
Temperature Contrasts: RCAO – HIRHAM



Response Contrasts: HADAM – ECHAM



Response Contrasts: RCAO - HIRHAM



Model Components

$$T_{i\,j\,k\,l} = \alpha_{i\,j\,k} + \beta_{i\,j\,k}\, I + \gamma_{i\,j\,k}\, I^2 + Z_{i\,j\,k\,l}$$

$$\alpha_{i\,j\,k} = \alpha + \alpha_i^{G} + \alpha_j^{R} + \alpha_k^{P} + \alpha_{i\,j}^{GR} + \alpha_{i\,k}^{GP} + \alpha_{j\,k}^{RP} + \alpha_{i\,j\,k}^{GRP}$$

α	overall mean	$\alpha_{i\,j}^{GR}$	effect of combining GCM i with RCM j
α_i^{G}	effect of GCM i	$\alpha_{i\,k}^{GP}$	effect of GCM i in Period k
α_j^{R}	effect of RCM j	$\alpha_{j\,k}^{RP}$	effect of RCM j in Period k
α_k^{P}	effect of Period k	$\alpha_{i\,j\,k}^{GRP}$	effect of combining GCM i with RCM j in Period k