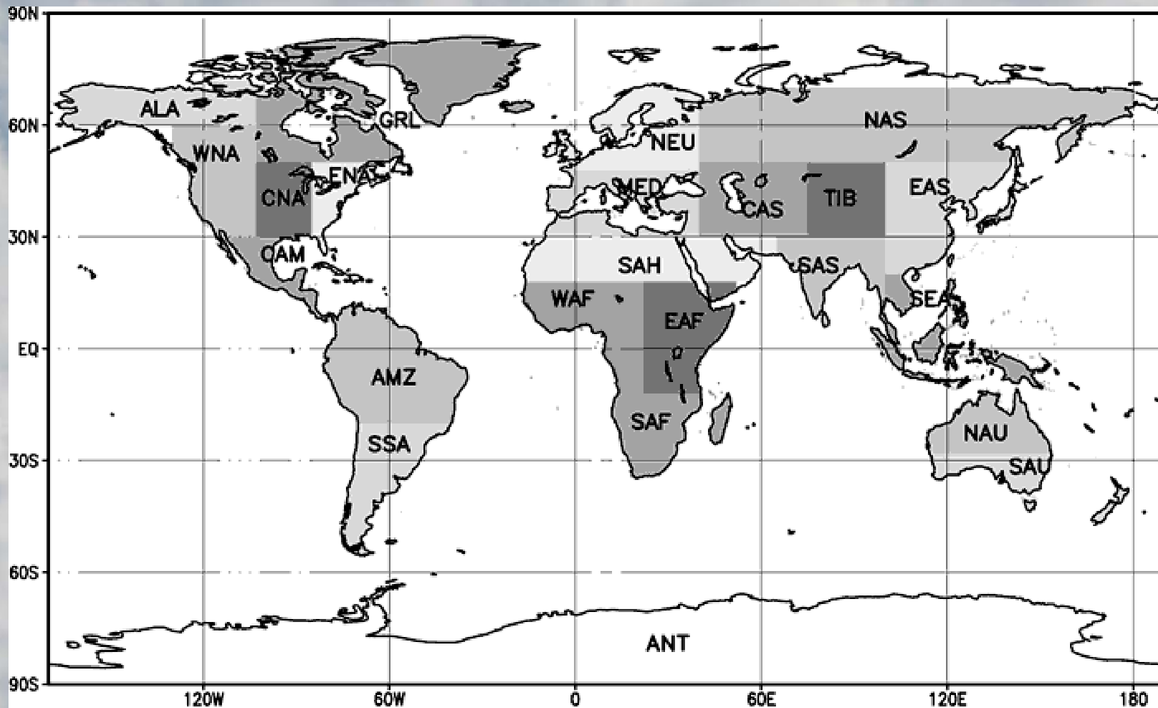
Performance-based multimodel probabilistic climate change scenarios

Arthur M. Greene, Lisa Goddard, Upmanu Lall
International Research Institute for Climate Prediction
The Earth Institute at Columbia University
Palisades, NY
amg@iri.columbia.edu

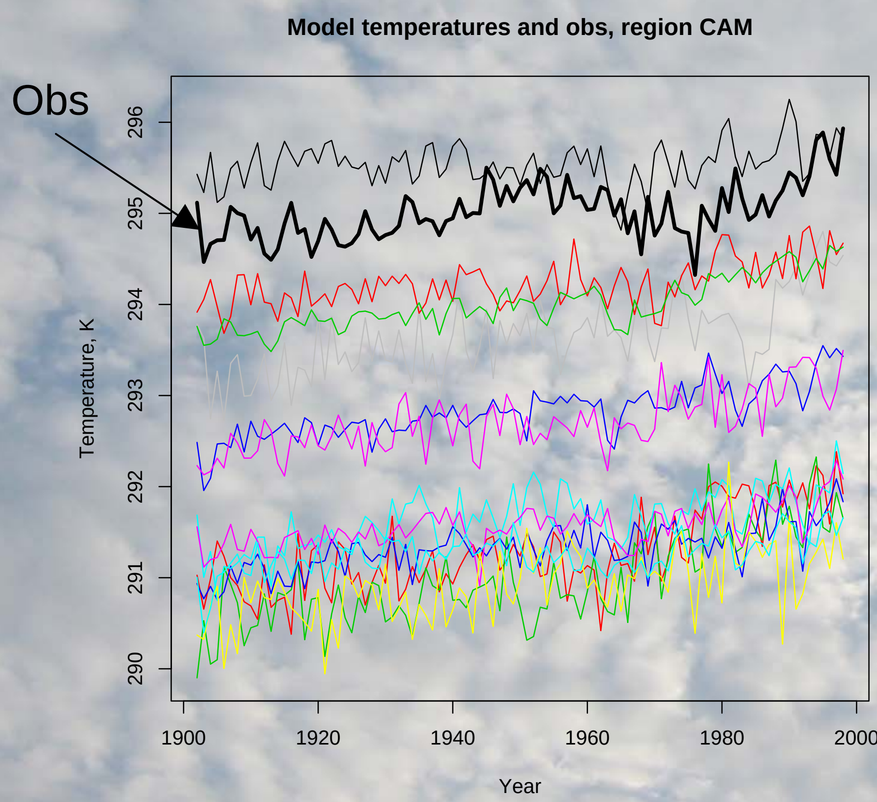
- Goal: Production of regional climate outlooks for the coming century
- Initial focus: Evolution of mean regional temperatures; eventually continuing with variability, precipitation…
- Methodology: Multimodel ensemble, combined in the framework of a linear Bayesian probability model
  - Coefficients derived by fitting to simulations of 20th-century climate (20C3M runs from IPCC AR4)
  - Bayesian estimation employed, in keeping with probabilistic framework
  - Model formulations with varying degrees of complexity explored

Regional definitions as in the IPCC SAR…

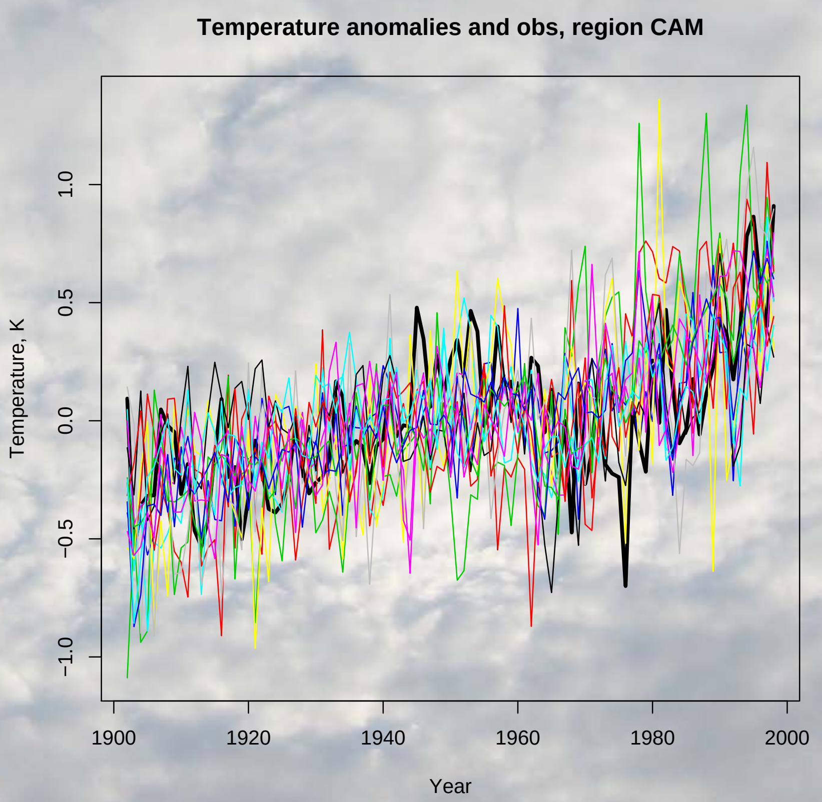


ALA	Alaska	NEU	Northern Europe	NAS	Northern Asia
WNA	Western North America	MED	Mediterranean	TIB	Tibet
CNA	Central North America	CAS	Central Asia	EAS	Eastern Asia
ENA	Eastern North America	SAH	Sahara	SAS	Southern Asia
GRL	Greenland	WAF	West Africa	SEA	South East Asia
CAM	Central America	EAF	East Africa	NAU	Northern Australia
AMZ	Amazonia	SAF	Southern Africa	SAU	Southern Australia
SSA	Southern South America	ANT	Antarctic		

AOGCMs may exhibit significant regional temperature biases

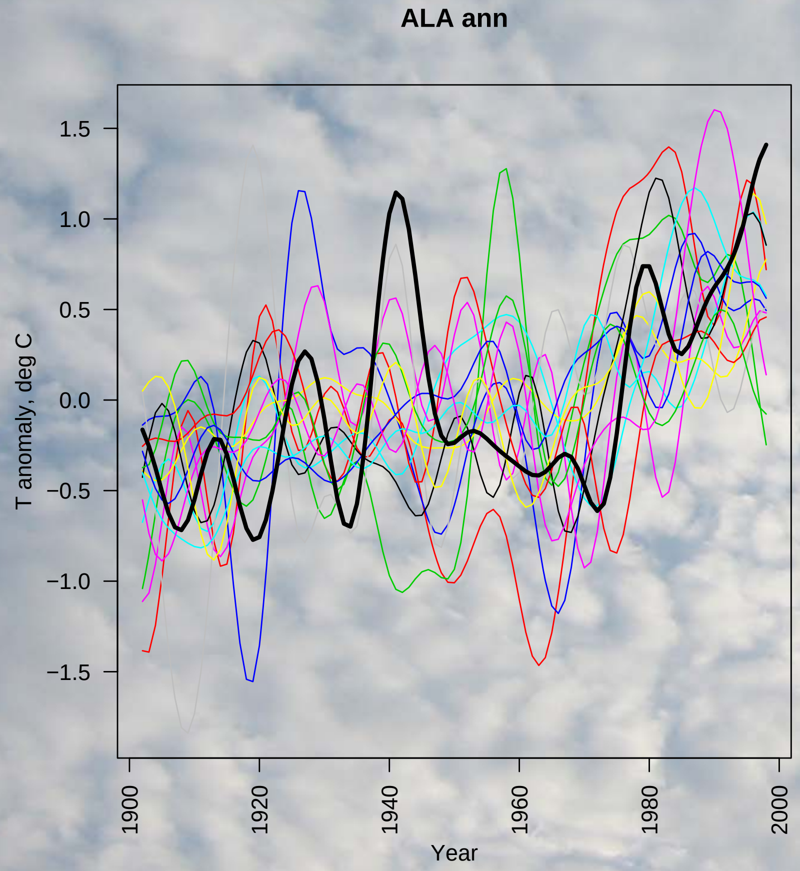


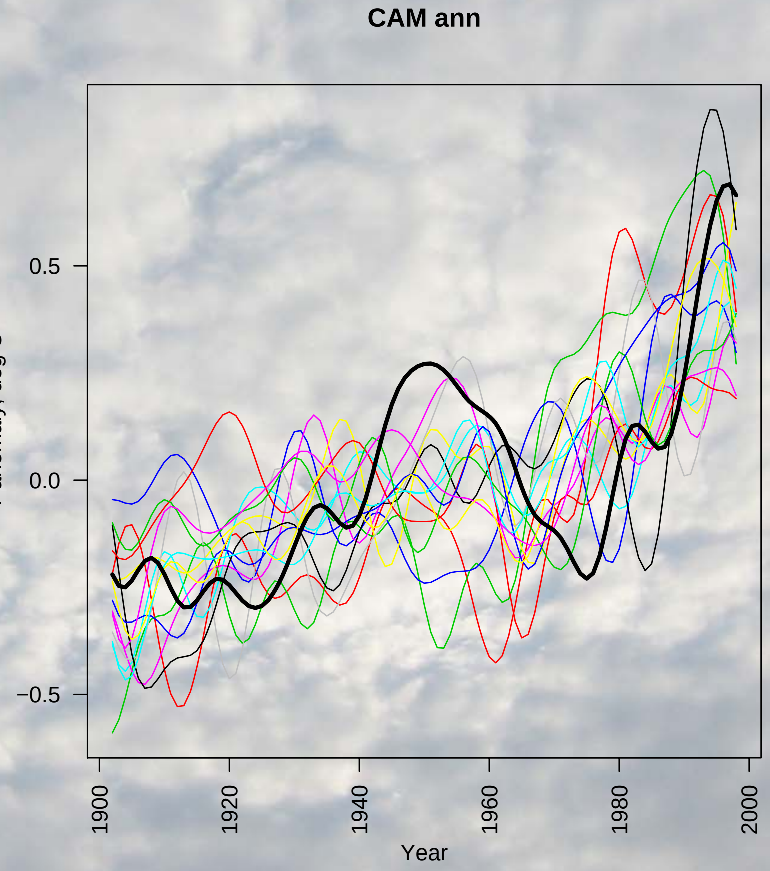
Central American sector (CAM), raw temperature series



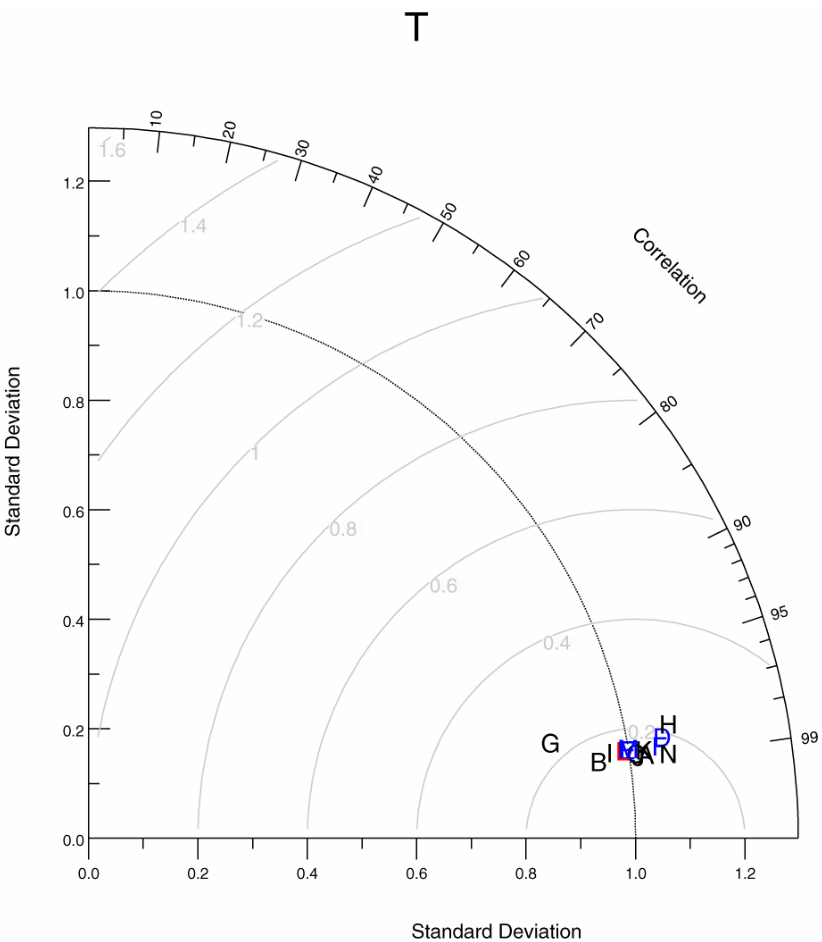
Anomalies (relative to each model's 1961-1990 climatology)

Incoherence not limited to interannual variations

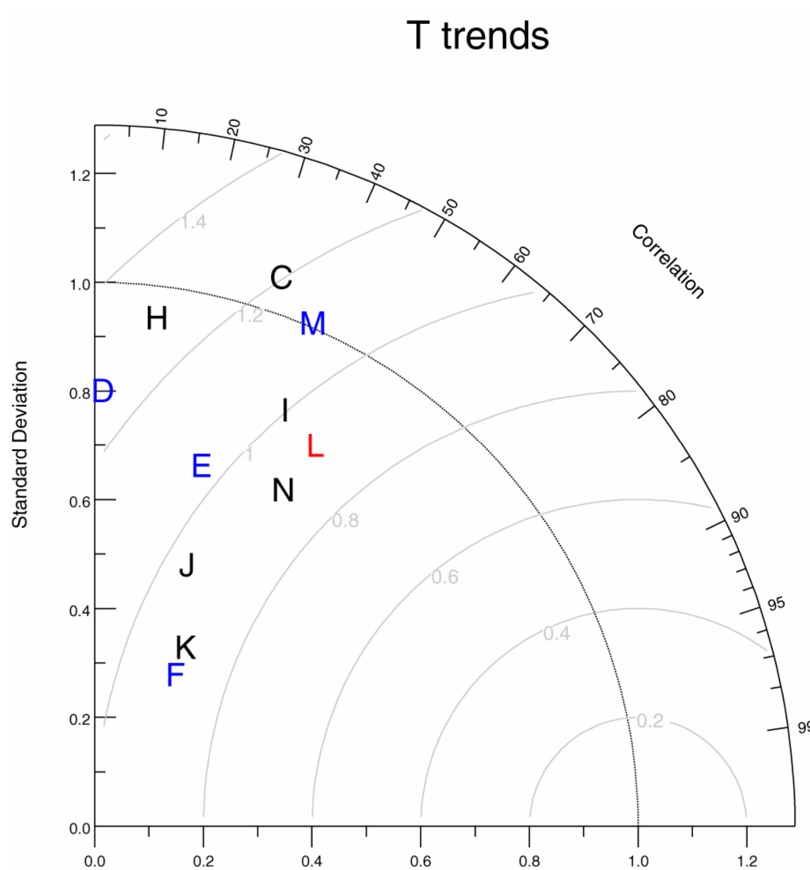




Mean regional temperatures are simulated with more fidelity than are regional temperature *trends.*



Regional annual mean T, 1961-1990



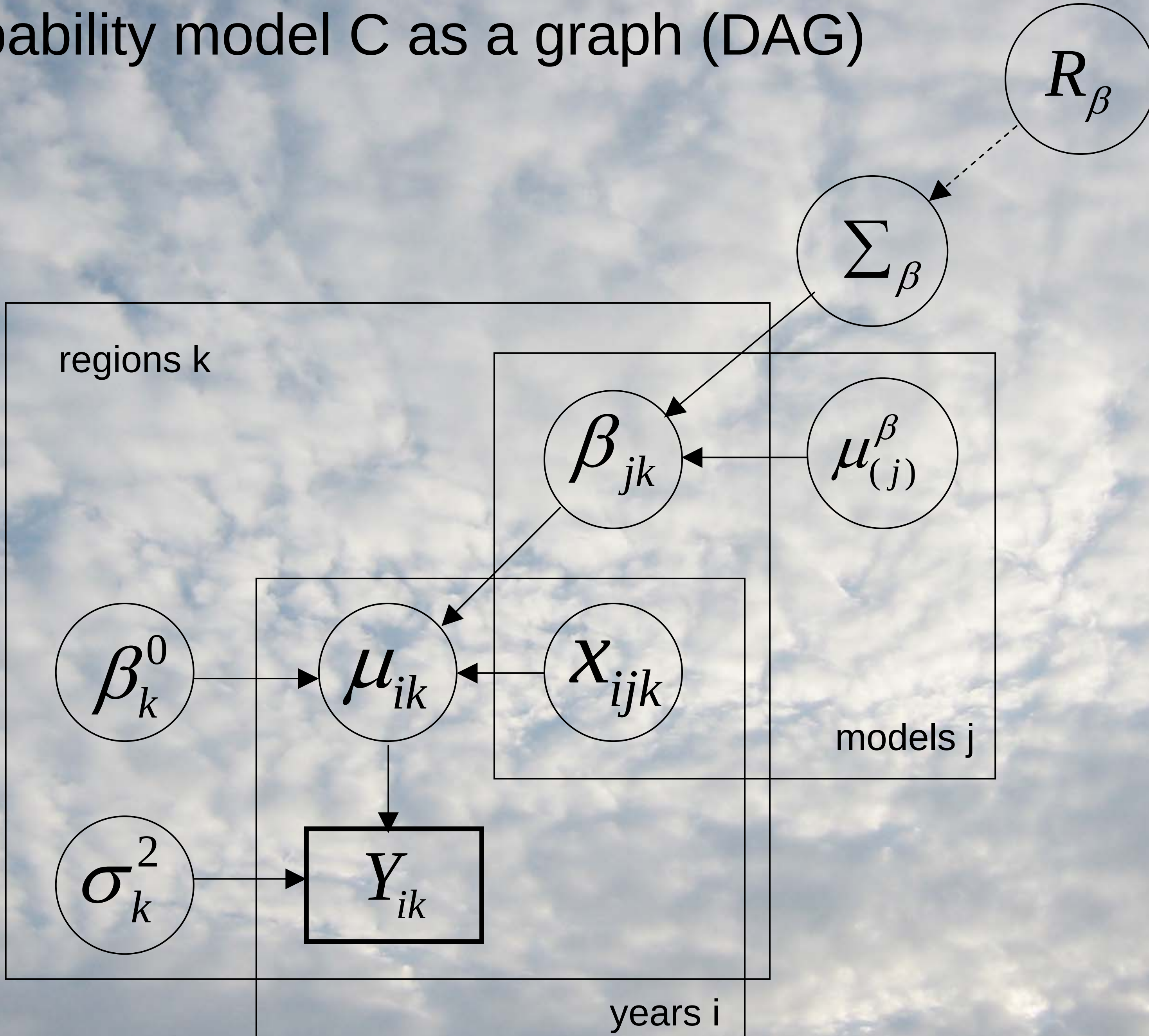
A: cccma_cgcm3
B: cnrm_cm3
C: csiro_mk3
D: gfdl_cm2_0
E: gfdl_cm2_1
F: giss_e_r
G: inmcm3_0
H: ipsl_cm4
I: miroc3_2
J: mpi_echam5
K: mri_cgcm2
L: ncar_ccsm3
M: ncar_pcm1
N: ukmo_hadcm3

Regional annual-mean T trends, 1965-1998

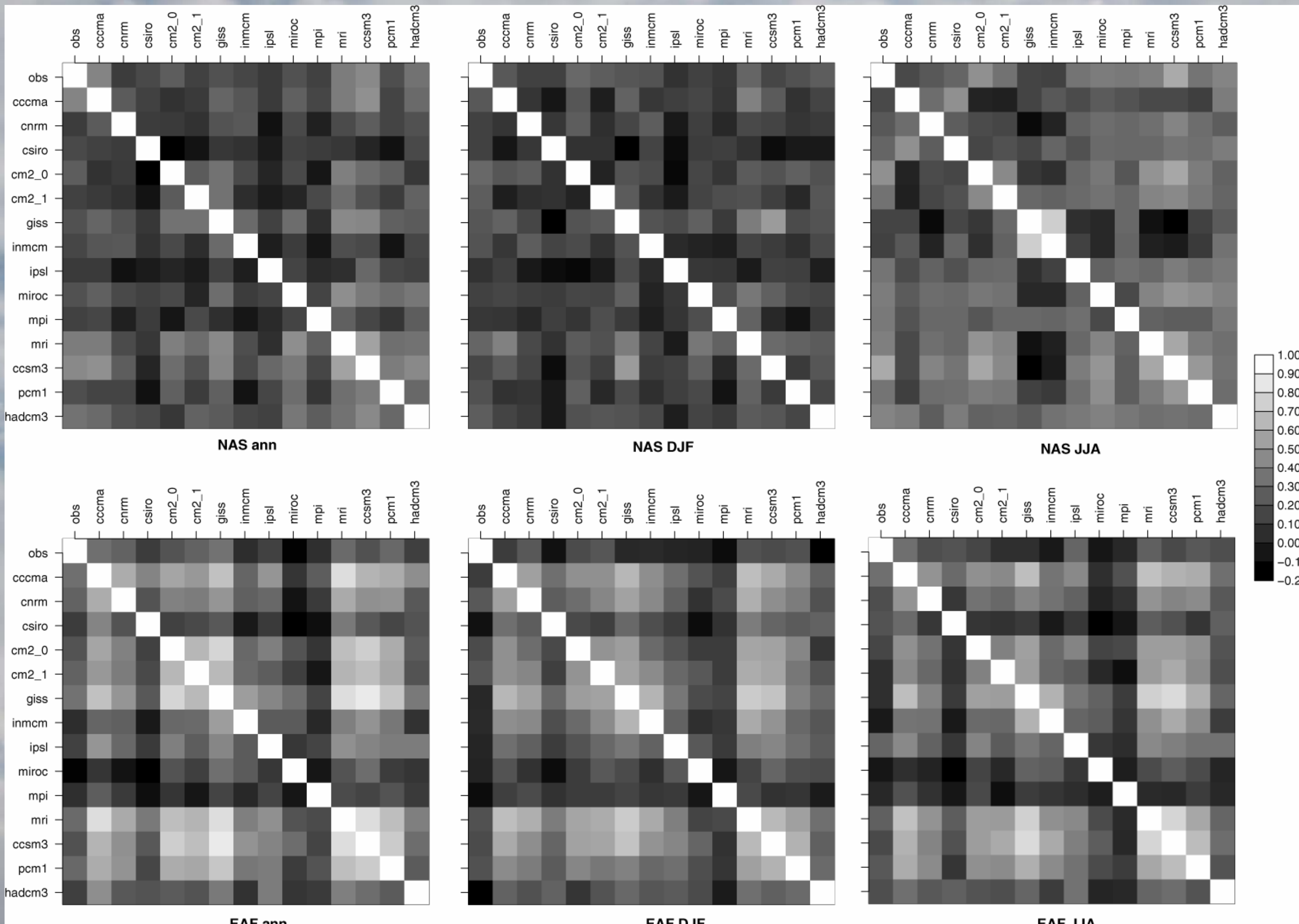
Probability model structures compared

- A $Y_{ik} \sim N(\mu_{ik}, \sigma^2)$ (variance of Y is uniform…)
- B: $Y_{ik} \sim N(\mu_{ik}, \sigma_k^2)$ (or regionally dependent…)
- C: $\beta_{jk} \sim MVN(\mu_\beta^{(j)} \Sigma)$ (cov(β) modeled explicitly)
- The last of these represents a multilevel, or hierarchical structure:
  - 1: Regional series of obs and simulations
  - 2: Global structure for parent distribution of β
- Priors are "diffuse" (i.e. non-informative) with the qualified exception of Σ, for which a scale matrix must be specified to at least an order of magnitude.

Probability model C as a graph (DAG)



Regional input covariance exhibits varying degrees of structure…



Some model comparison statistics (mean annual temperature)

Model	Dbar	Dhat	DIC	pD
A	2532	2217	2847	315.3
B	1768	1429	2108	339.4
C	1735	1505	1964	229.8

Dbar: Mean of the posterior deviance: mean $(-2 \log(p(y|\theta)))$

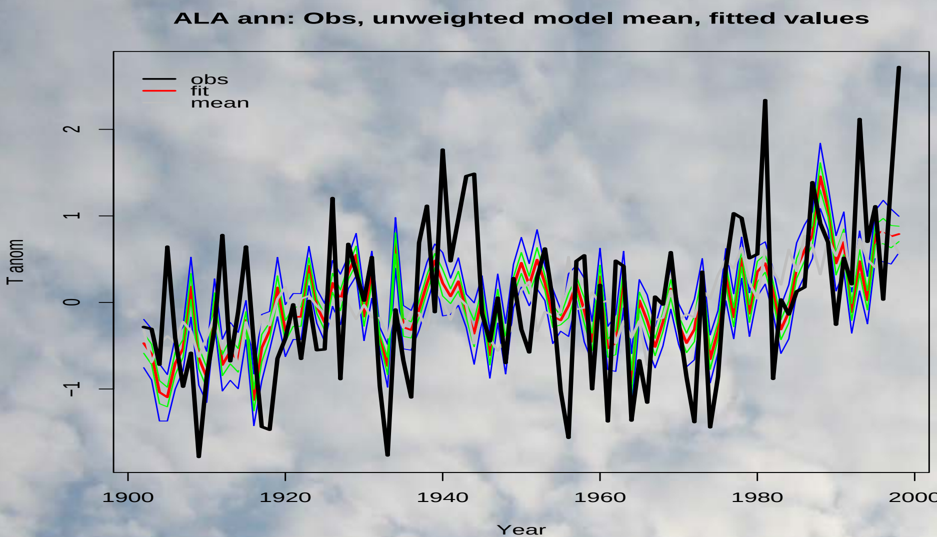
Dhat: Posterior deviance computed from mean θ: $-2 \log(p|(y|\theta_{bar}))$

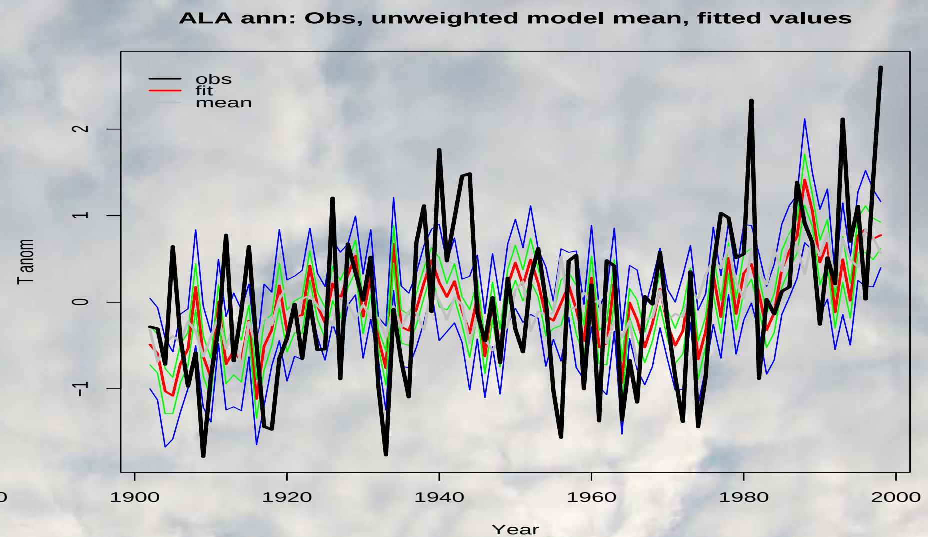
DIC: “Deviance Information Criterion,” an estimate of predictive skill.

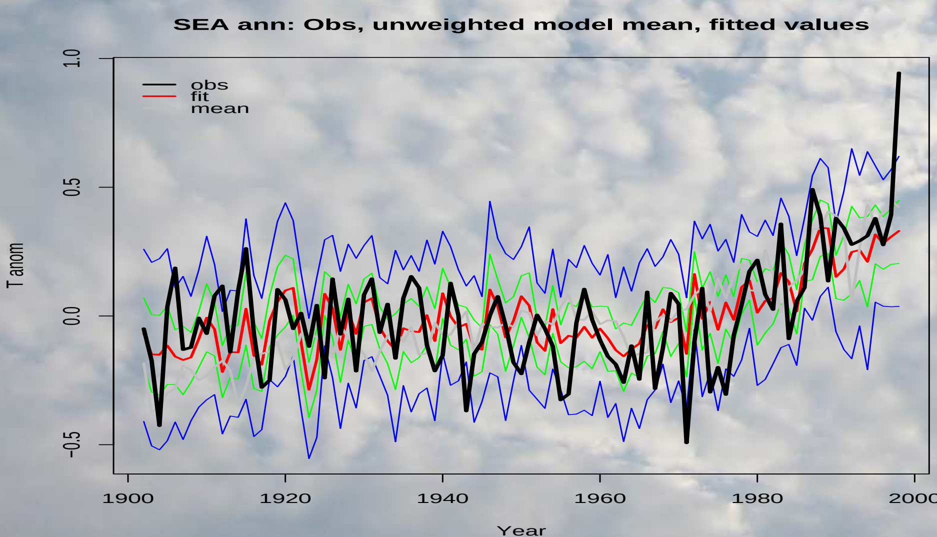
pD: Effective number of parameters in the model.

Conclusion: Model B a lot better than A; C a little better than B

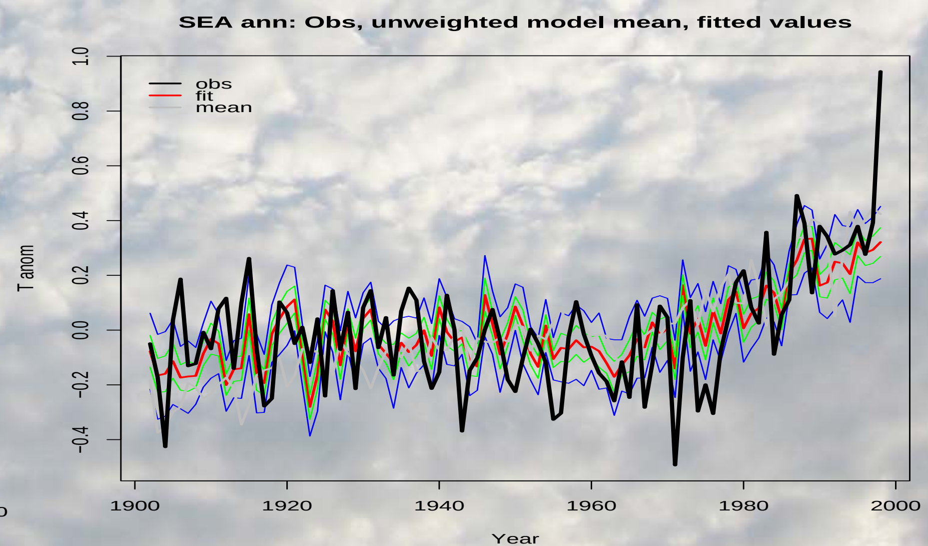
Some fitted series…





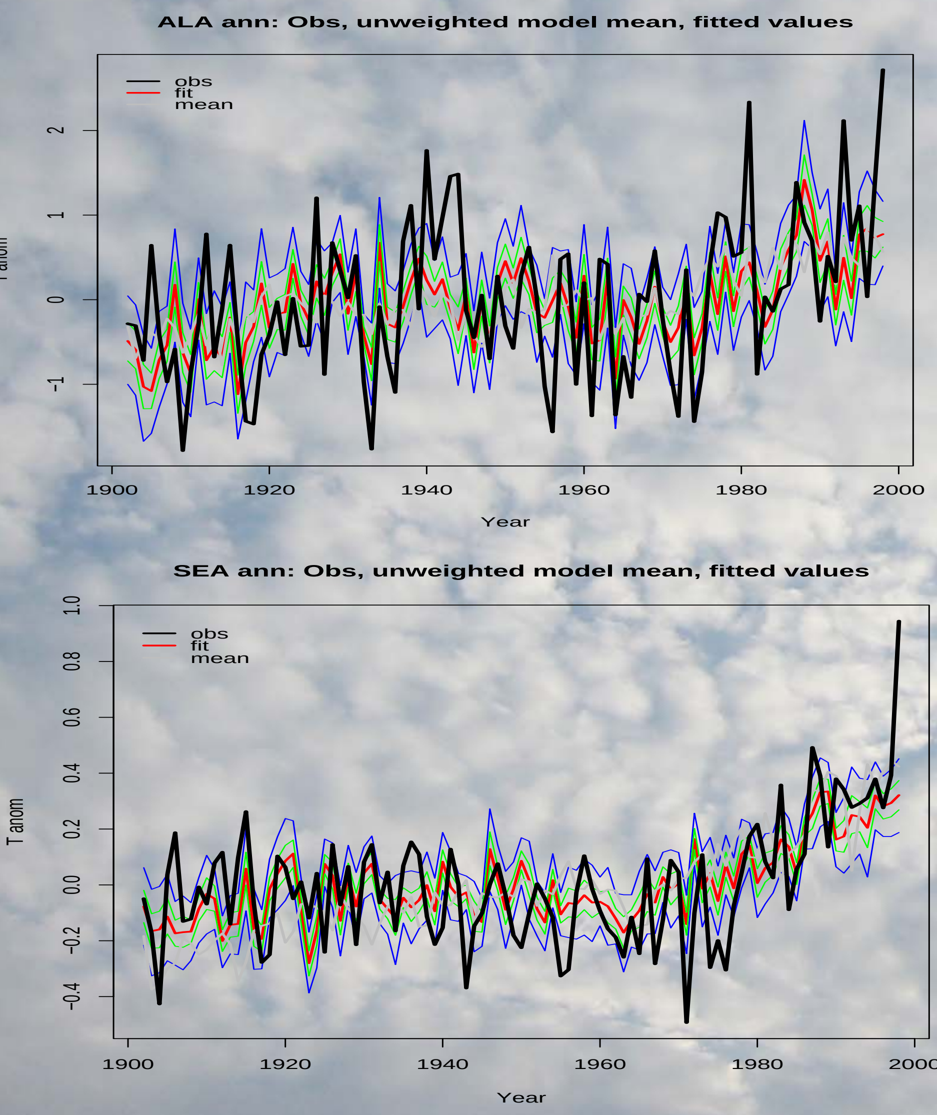


Model A

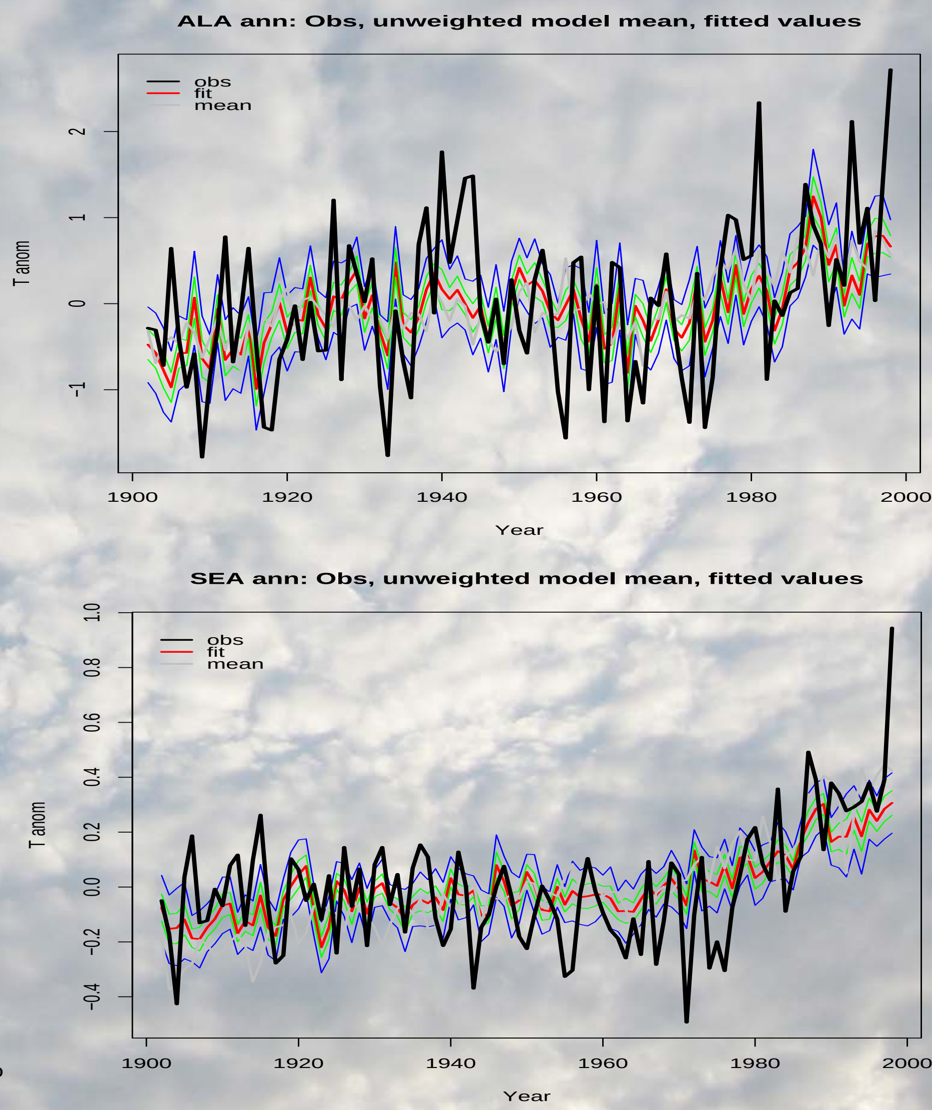


Model B

Fitted series, cont'd

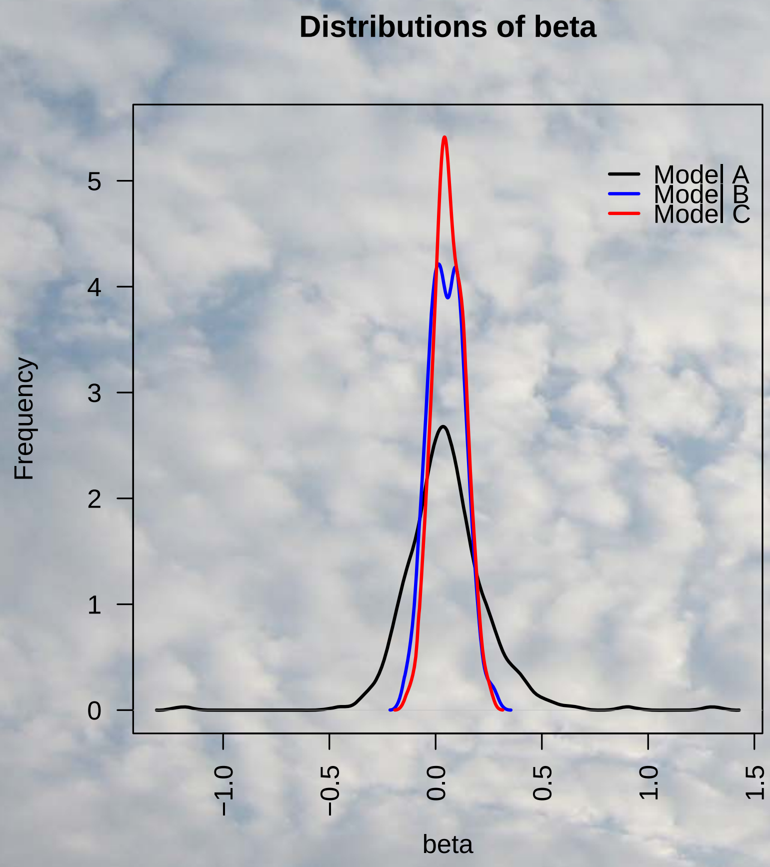


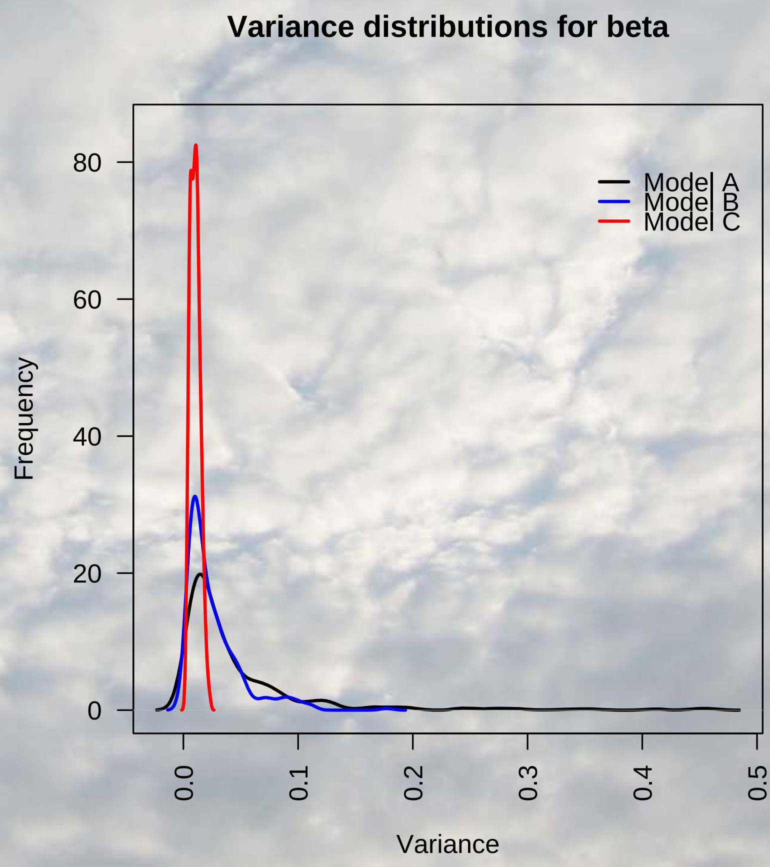
Model B



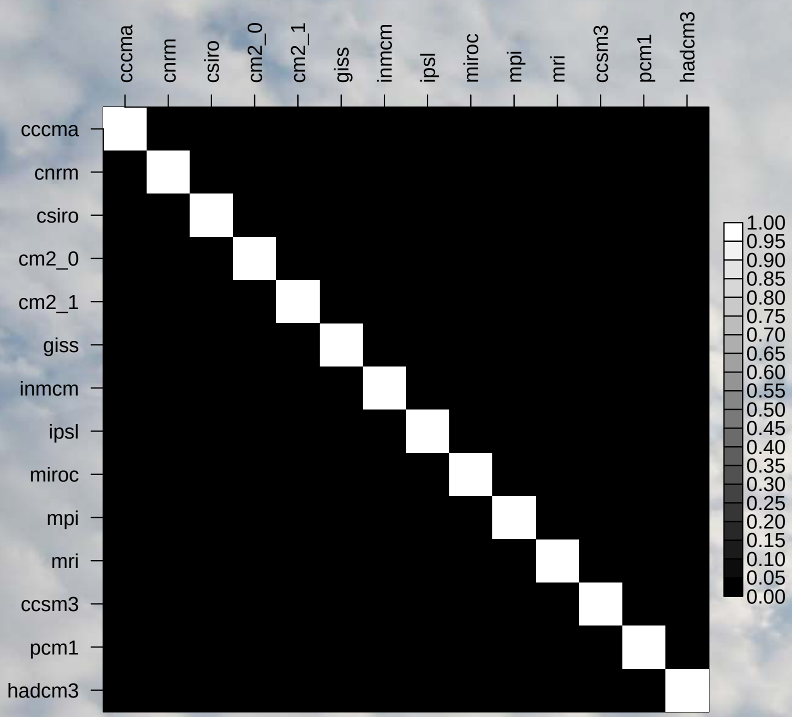
Model C

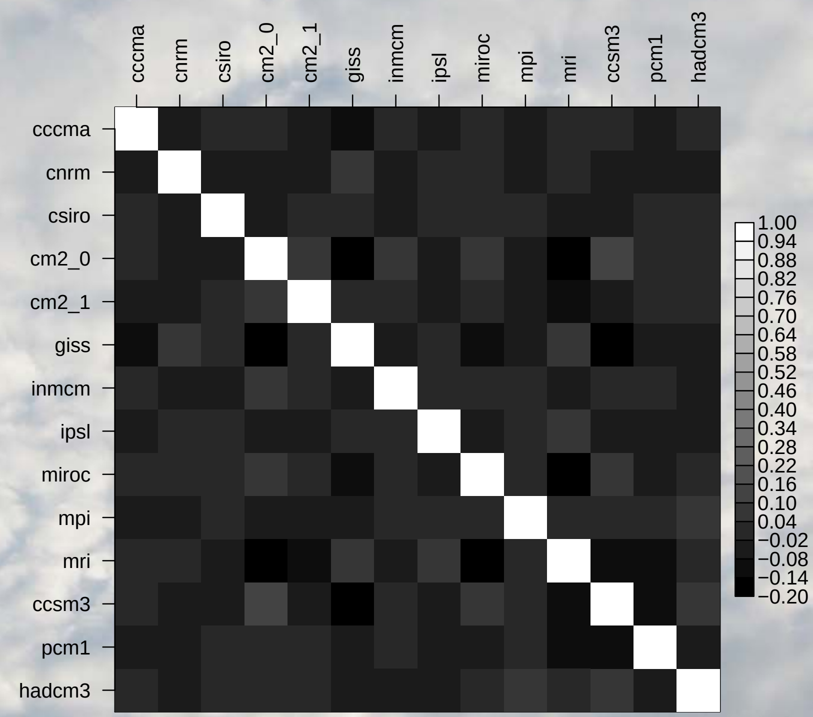
Model structure and estimation of β_{jk}





Prior distribution of cov(β) is "imprinted" by the data





Prior correlation for β:

A blank slate.

Posterior correlation:

(Weak) structure is present

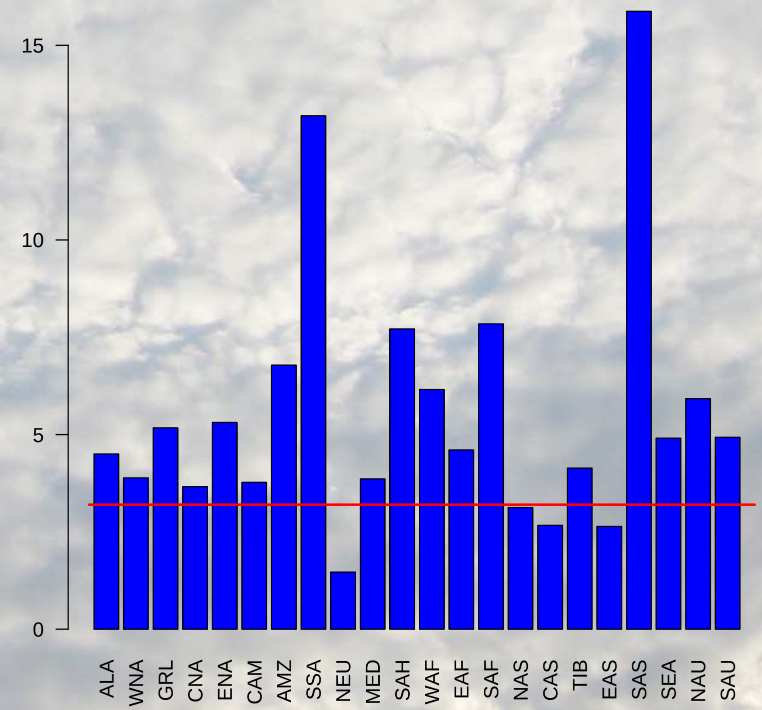
Cross-validation

- Computed with respect to decadal means
- “Leave-10-out”, with model fitted to remaining data. Nine values / region

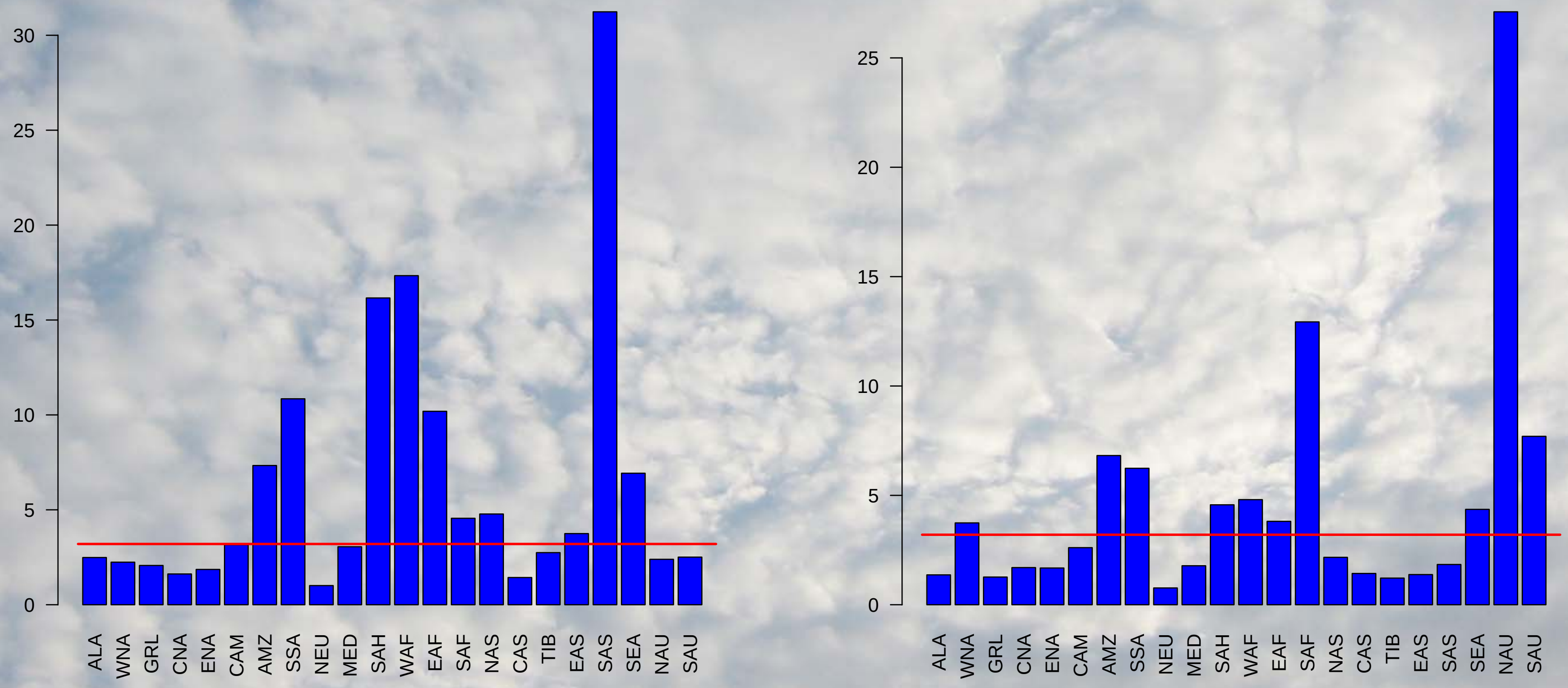
Comparison over all regions

Season	F	P ($\nu_1=\nu_2=198$)
Ann	4.38	1.16E-23
DJF	2.58	3.05E-11
JJA	3.32	1.22E-16

Region by region (annual mean)

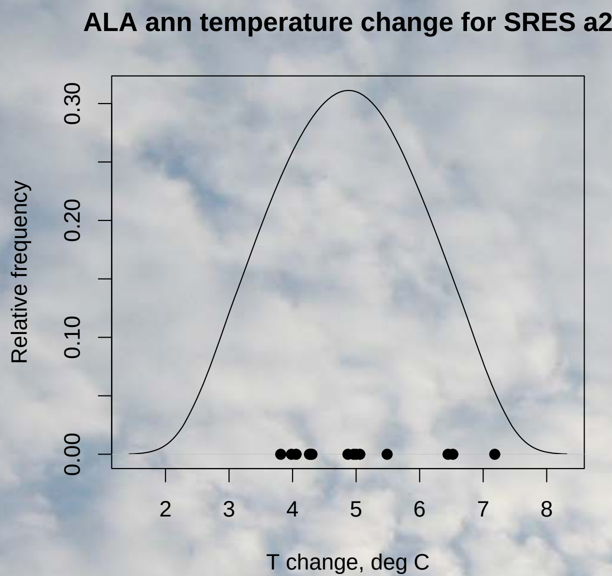


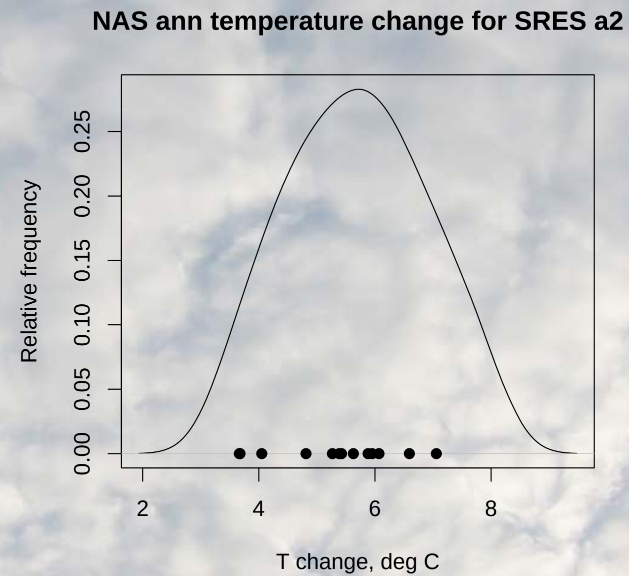
DJF, JJA…

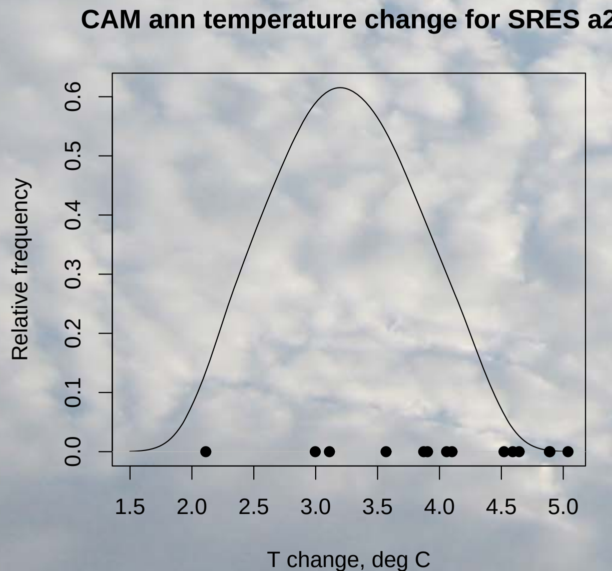


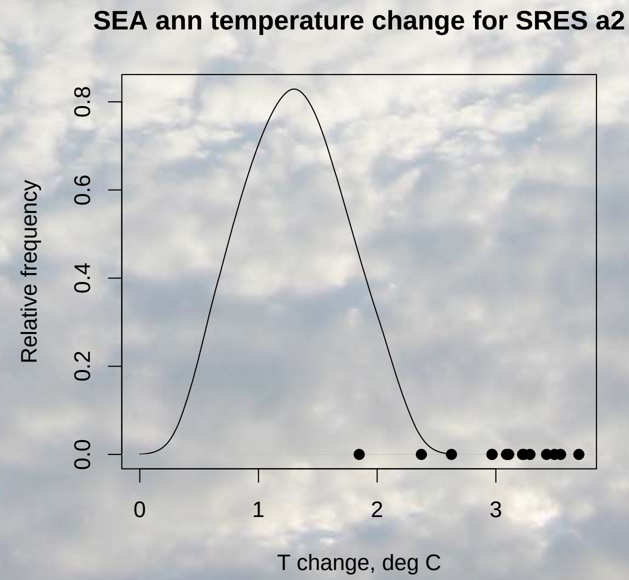
0
5
10
15
20
25
30
ALA WNA GRL CNA ENA CAM AMZ SSA NEU MED SAH WAF EAF SAF NAS CAS TIB EAS SAS SEA NAU SAU
0
5
10
15
20
25
ALA WNA GRL CNA ENA CAM AMZ SSA NEU MED SAH WAF EAF SAF NAS CAS TIB EAS SAS SEA NAU SAU

Coefficients are applied to the SRES scenario simulations to generate the final temperature projections

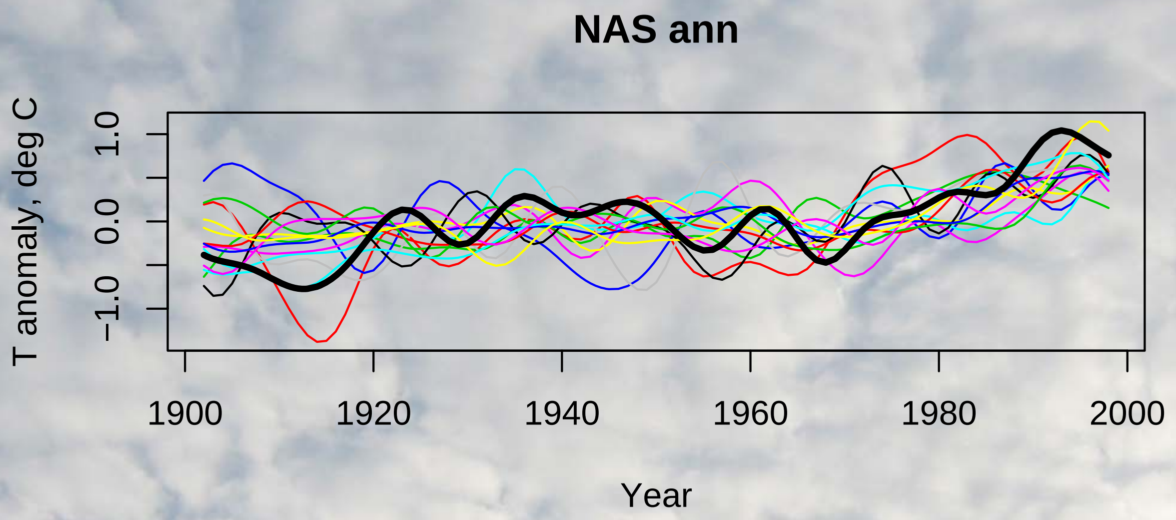


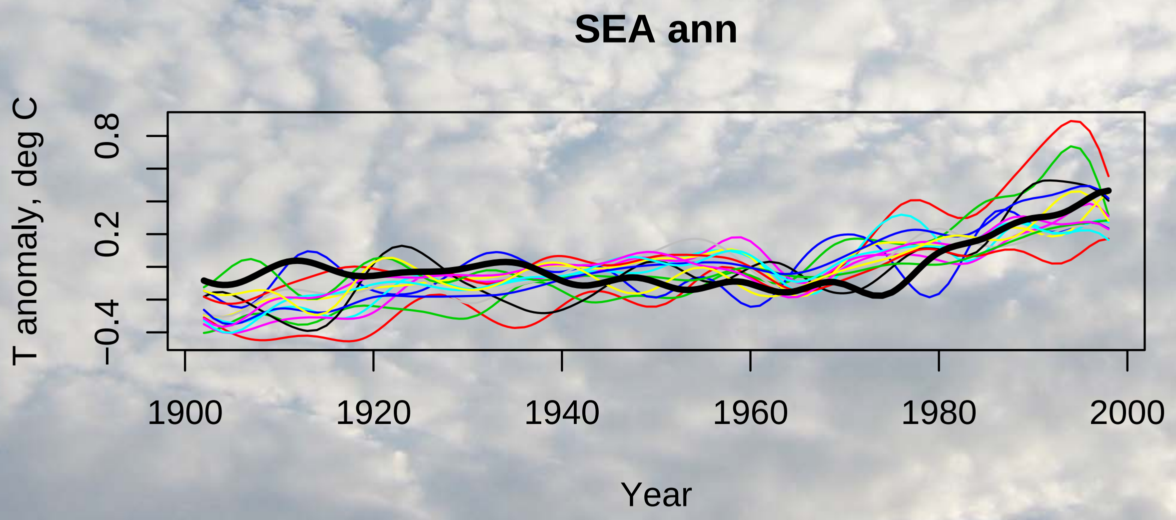






Stationarity assumptions cannot be ignored…





Summary

- Regional temperature projections are generated for the 21st century
- Based on IPCC 20C3M experiments, SRES scenario simulations
- AOGCM outputs combined in the framework of a Bayesian hierarchical linear model of limited complexity
- Relaxation of constraint that $\sum_j \beta_{jk} = 1$ allows resultant to "escape the envelope" of the underlying simulations
- Projections appear to be an improvement over the unweighted mean of the contributing AOGCMs. This improvement is greatest for the annual mean, decreasing but still present for DJF and JJA
- There is an implicit assumption of stationarity, and with this comes the unavoidable responsibility of choosing good (or at least defensible) assumptions in model building. So what else is new?