A COMPARISON OF SEVERAL GCM SIMULATIONS OF SEASONAL TEMPERATURES OVER CENTRAL EUROPE

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SUMMARY

The presented contribution tries to compare simulated and observed temperature fields over Central Europe on the basis of seasonal averages. Simulated temperature fields are represented by the results of four coarse-grid GCMs (DKRZ, GFDL, Hadley Center, NCAR). Besides 7 control runs (1xCO_2) there are also results from five transient greenhouse simulations, and from two 2xCO_2 equilibrium simulations. Observed fields are constructed from 109 stations for the period of 1971-1980 in two ways. Processed area includes 21 gridpoints in T21 gaussian grid (5.6x5.6 degrees of horizontal resolution). The similarity of patterns was studied by correlation coefficients, the absolute differences between the fields were described by the RMS error. Almost all models qualitatively well simulate general spatial distribution of temperature over Central Europe except summer season, patterns of temperature fields remain very similar even after CO_2 doubling. For some models simulated temperature gradients are not realistic and simulated temperatures mostly underestimate the real ones. However, in absolute values there are significant differences even between similar model versions.

KEY WORDS

General circulation models - seasonal temperature - Central Europe

INTRODUCTION

General circulation models (GCMs) are the most sophisticated tools currently available for estimating the likely future effects of increasing greenhouse gasses (GHG) concentrations on climate. They simulate the major mechanisms affecting the global climate system according to the laws of physics, producing estimates of climatic variables for a regular network of gridpoints in the global scale.

Generally there exist two types of model experiments (runs). "Control" runs use present day concentrations of GHG and they simulate the present day climatic conditions. In "greenhouse" experiments the concentration of GHG (expressed in CO_2 equivalent) is increased, either gradually or instantaneously. The differences between the control run and the anomaly run represent the response to increased greenhouse effect.

So far GCMs have been used to conduct two types of greenhouse experiment for estimating future climate: equilibrium response and transient forcing experiments. Equilibrium response experiments are computed for an abrupt increase (commonly, a doubling) of atmospheric concentrations of CO_2. Such a step change in atmospheric composition is unrealistic, however a sensitivity study can be performed with such a model. Transient forcing experiments expect that the concentration of GHG is increasing gradually. Such "time dependent" experiments attempt to simulate the evolution of climate.

One of the basic problem of climate modelling is connection of atmospheric GCMs with oceanic models. In some models only shallow "mixed" oceans layer is used, on the other hand in the most realistic "coupled" models deep ocean layers are included (Houghton et al., eds., 1990).

USING OF GCMs OUTPUTS ON REGIONAL LEVEL

GCMs are not yet sufficiently realistic to provide reliable predictions of climatic change at the regional level, and even at the global level model estimates are subject to considerable uncertainties. They are unable accurately to reproduce even the seasonal pattern of present day climate at a regional scale (Carter et al., 1992). GCM outputs thus represent broad-scale sets of possible future climatic conditions and should not be regarded as predictions.

Results of some models for Europe are considered in Climate of Europe (1995). Many features are similar, but there are also differences. According to the European modelling centers (Hadley and Max Planck Institute) the increase in winter temperatures generally lie between 0 and 4 degrees with largest values in Northern Scandinavia. In summer, temperatures increase by 0-3 degrees over Europe with largest values over southern and central Europe. The large-scale temperature patterns simulated with GFDL and NCAR models are similar to the above mentioned results, but the simulated global average temperature increase after CO_2 doubling is higher than those computed with the

European models: 2.3 ^{o}C as compared to 1.3-1.9 ^{o}C (Houghton et al., eds., 1992, Gates et al., 1993).

Practically in all central European countries attempts were made to downscale the results of GCMs to regional level. For the former Czechoslovakia outputs from four models were interpolated to higher resolution grid (0.5x1.0) in GIS RAINS IIASA and maps of equilibrium changes were constructed for temperature and precipitation by Brázdil (1992). Results of various GCM outputs for the former CSFR are evaluated by Kalvová and Brázdil (1993). Regional scenario for the Czech Republic was constructed by Kalvová and Nemešová (1994) as a part of US Country Study Program. In this paper outputs from GISS model are recommended, in some cases good results are given by CCCM model. GISS model is able to reproduce annual course of temperature, however simulated values for $1xCO_2$ and $2xCO_2$ must be smoothed at first. This is in agreement with the results for Poland (Liszewska, personal communication). In Hungary problem of downscaling for regional climate scenario construction is solved in different way. Mika (1994) combined various sources of information (instrumentally measured, historical and paleo-proxy data) and also simple regional energy and water balance model to estimate the diagnostic relationships between climate variations at the regional vs. hemispherical scales. For Slovakia regional climate change scenario based on GCM outputs was also constructed (Nieplová et al., 1995)

MATERIAL USED

In the present paper the ability of four coarse-grid GCMs to simulate present temperature fields over Central Europe as well as their response to enhanced greenhouse forcing is studied. Data are distributed by Working Group 1 of IPCC and they origin from four modelling centers - DKRZ (Deutches Klimarechnenzentrum, Hamburg, Germany), GFDL (the Geophysical Fluid Dynamics Laboratory, Princeton, USA), Hadley Center (Bracknell, UK) and NCAR (the National Center for Atmospheric Research, Boulder, USA).

There are results from five transient greenhouse simulations, from two $2xCO_2$ equilibrium simulations, and from the seven corresponding control runs. In the two equilibrium experiments (GFDL and Hadley) only shallow mixed-layer oceans were used instead of the oceanic GCMs. These two models are further referred as a "mixed", the other models are referred as a "coupled". In the case of NCAR model, two runs for different time slice were performed, both referred as a NCAR65 and NCAR75. In majority of tables and figures the latter version is used, then reffered as NCAR only. Basic information about each model is summarized in Table 1.

Experiment	Horizontal resolution	CO_2 control [ppm]	Years control	CO_2 greenhouse	Years greenhouse
OPYC	T21=5.6x5.6	390	64 - 73	IPCC scenario A	64 - 73
LSG	T21=5.6x5.6	390	64 - 73	IPCC scenario A	64 - 73
GFDL transient	R15=4.5x7.5	300	1 - 100	+1 % /year compound	61 - 80
GFDL equilibrium	R15=4.5x7.5	300	1 - 100	600 ppm	61 - 80
Hadley transient	2.5x3.75	323	66 - 75	+1 % /year compound	66 - 75
Hadley equilibrium	5x7.5	323	66 - 75	646 ppm	66 - 75
NCAR65	R15=4.5x7.5	330	61 - 70	+1 % /year linear	61 - 70
NCAR75			71 - 80		71 - 80

Table 1. Description of the investigated models. OPYC and LSG are from DKRZ and they are named after their oceanic component

Table 1 shows some differences among compared models - especially in CO_2 level of control runs. Regardless of the original resolution all results were interpolated to T21 gaussian grid in the DKRZ. Data are used with seasonal resolution and not all models have results for all seasons and the annual values. Surface air temperature is processed in the present study, but in various models the representation of this quantity is different. Surface air temperature at two meters above the surface was available only for DKRZ models. For GFDL and NCAR the temperature at the lowest model level (roughly 80 meters) was used. For Hadley model the only available temperature was that of the actual earth or sea surface (Räisänen, 1994). Processed area is represented by 21 gridpoints over Central Europe (see Fig. 1).

COMPARISON OF CONTROL RUNS WITH OBSERVATIONS

At first, the ability to reproduce present temperature patterns is described. To do this it is necessary to find a proper representation of observed data. Verification of the control state is performed against temperature averages at 109 stations, observed in the period 1971-1980 (World Weather Records, 1971-1980, 1987). Used period can influence the absolute differences in compared fields but has almost no meaning for spatial pattern comparison.

There were chosen two approaches how to represent observations - both are briefly described in supplement I. The first approach - continental - is based on a construction of a "hyperplane" where air temperature is expressed as a dependent variable of three independent variables - latitude, longitude and altitude. General equation is computed from 109 used stations. Then the equation is solved for 21 gridpoints. The local approach is based on a computation of unweighted areal averages for each rectangle around the gridpoints. These areal averages were finally corrected by the altitude - they were recalculated to the sea level. Whereas the continental approach describes large scale temperature patterns, the local approach is more sensitive to local peculiarities in the spatial temperature distribution.

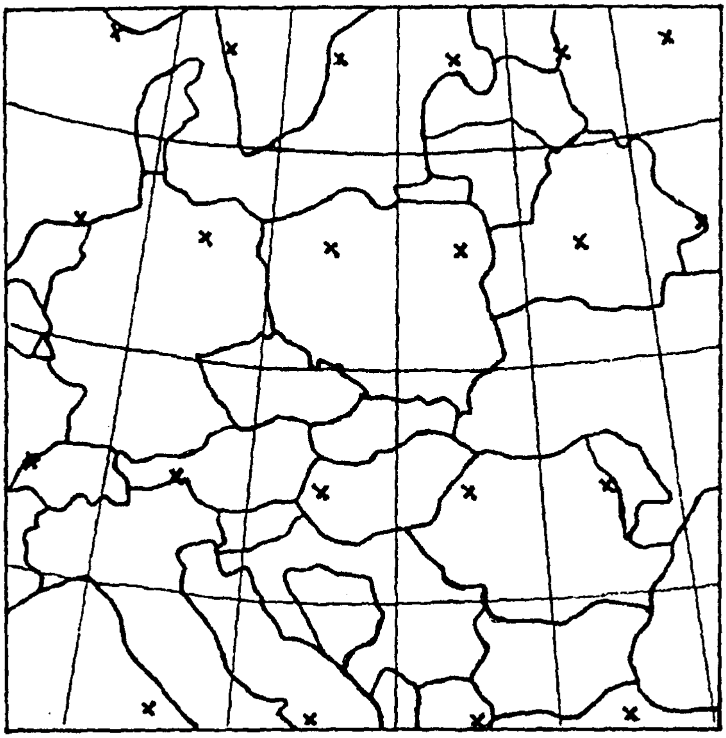

Fig. 1. Investigated area of Central Europe with 21 processed gridpoints

From the comparison of both approaches it follows that according to average values for 21 gridpoints continental approach gives lower values for all seasons and annual data. However, when compare patterns they are very similar in both cases.

The similarity of simulated and observed fields is primarily measured with two statistics: correlation coefficient and root-mean-square error (RMS). The RMS is computed according to the following equation:

$$RMS = \sqrt{\frac{1}{N} \sum_{i=1}^{N} (S_i - O_i)^2},$$

where N - number of gridpoints

S - simulated temperature for the gridpoint i
O - observed temperature for the gridpoint i.

Results of comparison of observed and simulated temperature fields are summarized in Table 2. Whereas correlation coefficient is a measure of the similarity of patterns, RMS measures the magnitude of the absolute differences between two fields, therefore it is sensitive to systematic errors. As indicated by high correlation coefficients, almost all models quantitatively well simulate general spatial distribution of temperature over Central Europe. For summer correlation coefficients are smaller and it is probably caused by the fact, that in summer the effects of large scale circulation patterns are less developed.

Examples of observed and simulated temperature fields for winter and summer can be seen on Fig. 2a,b. High correlation coefficients (except summer) show good coincidence in spatial pattern distribution. On the other hand, the simulated gradients in temperature fields are sometimes not realistic (e.g. LSG and Hadley for winter).

Model		Coupled						Mixed	
		OPYC	LSG	GFDL	Hadley	NCAR65	NCAR70	GFDL	Hadley
winter	Correlation	.96	.88	.93	.90	.95	.94	.95	.88
	RMS error	3.3	3.2	2.4	9.1	5.6	4.7	2.7	7.2
spring	Correlation	.97	.94			.91	.94		
	RMS error	2.9	2.0			4.3	5.0		
summer	Correlation	.92	.66	.81	.89	.59	.51	.79	.96
	RMS error	1.2	3.8	1.7	1.8	5.6	5.5	2.1	.7
autumn	Correlation	.96	.95			.95	.96		
	RMS error	1.2	2.0			1.6	1.4		
annual	Correlation	.99	.94						
	RMS error	1.7	1.4						

Table 2. Statistical comparison between the observed and simulated surface or near-surface temperatures. The unit for RMS error is K

On Fig. 3 areal averages for observation and simulated fields are compared. At first sight systematic shift of simulated temperatures to lower values can be seen, especially for winter and spring. It means that simulated temperatures underestimate the real ones for some seasons. Also RMS errors are higher in some cases. Inherent systematic errors, that appear in each model, can be regulated via flux correction between ocean and atmosphere (Meehl, 1994). From used models more sensitive flux correction is used by DKRZ models, then GFDL and Hadley. There is no flux correction in NCAR models. Differences between areal averages of the different versions of the same modelling centers are summarized in Table 3 and they are sometimes significant.

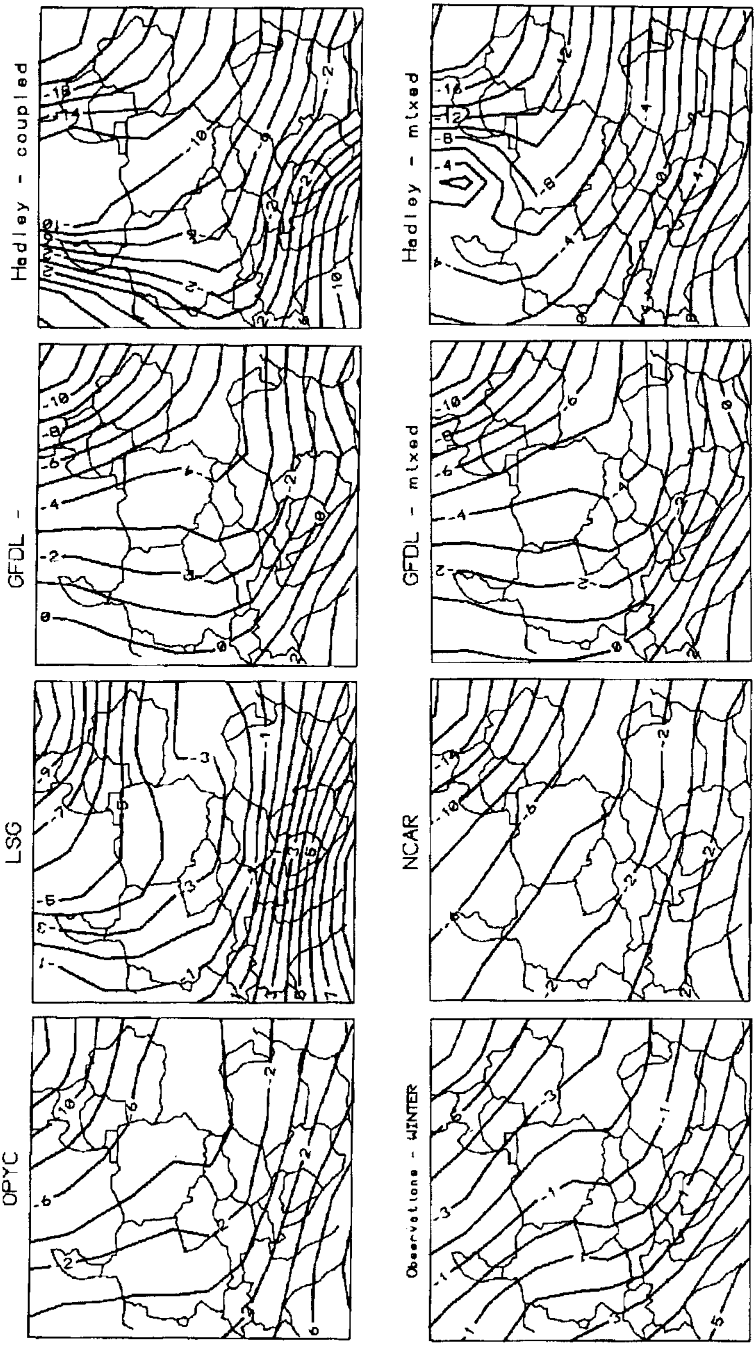

Fig. 2a. Observed and simulated temperature fields for Central Europe - winter

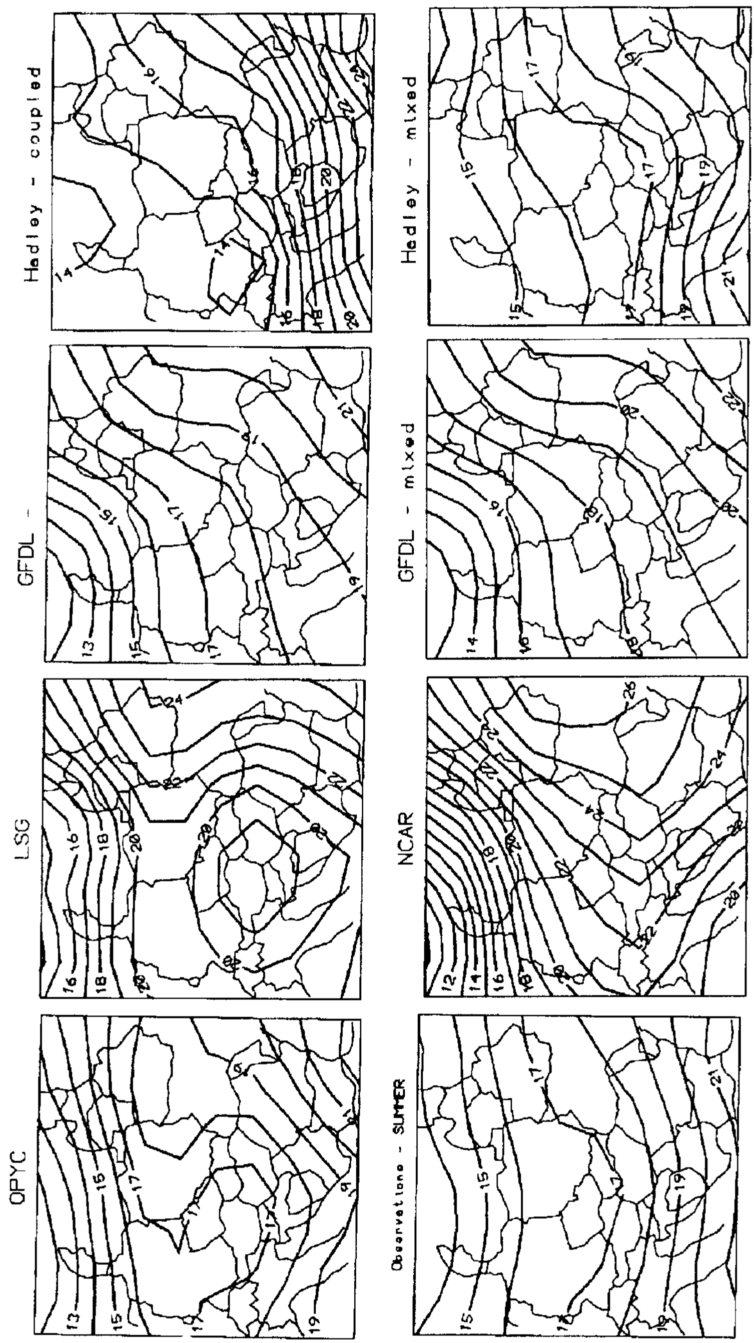

Fig. 2b. Observed and simulated temperature fields for Central Europe - summer

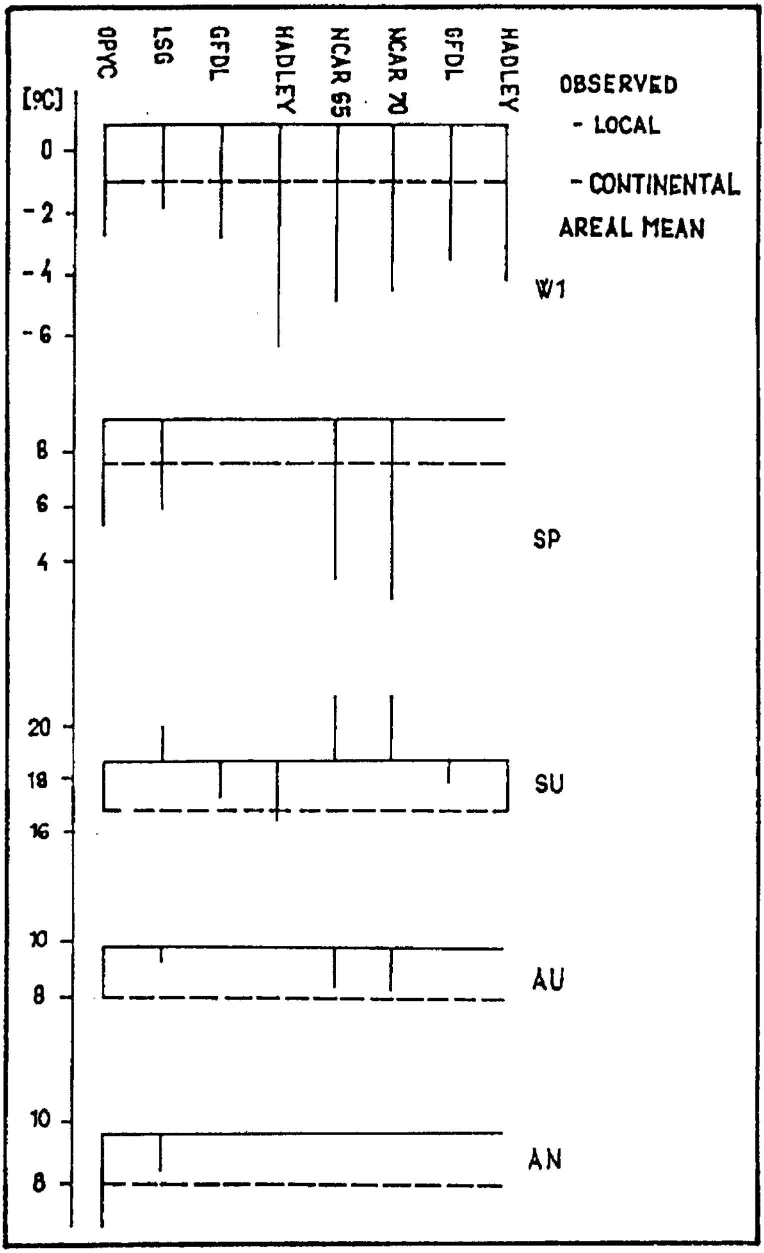

Fig. 3. Comparison of areal averages between observations (horizontal lines) and control runs (vertical bars)

Control runs	WI	SP	SU	AU	AN
DKRZ (OPYC-LSG)	-0.9	-1.1	-3.2	-1.8	-1.7
GFDL (COUPLED-EQ)	0.4		-0.7		
Hadley (COUPLED-EQ)	-2.2		-0.1		
NCAR (75-65)	0.5	-0.7	-0.3	0.1	

Table 3. Differences between areal averages of the similar models versions (control runs) in K for all seasons and annual values

CLIMATE CHANGES INDUCED BY INCREASING CO_2

The second aim of this contribution was to describe the response of the used models to CO_2 forcing. As in the previous section, spatial temperature patterns were compared and absolute increase in temperature was also studied. When compare corresponding versions ($1xCO_2$ and $2xCO_2$) on Fig. 4 it can be seen, that the distribution of the temperature over Central Europe remains practically the same after doubling CO_2 according to the used models. Average increase of temperature for the whole processed area can be seen on Fig. 5 for each season. Generally, the investigated models give larger increase for winter, but this difference is in a range of 1-2 K for each model.

Changes	WI	SP	SU	AU	AN
DKRZ (OPYC-LSG)	0.9	-0.9	-0.4	0.7	0.2
GFDL (COUPLED-EQ)	-2.2		-1.2		
Hadley (COUPLED-EQ)	-0.2		-0.7		
NCAR (75-65)	0.5	0.0	-0.6	-0.5	

Table 4. Differences between areal averages of similar model versions ($2xCO_2$) in K for all seasons and annual values

In Table 4 differences of areal average temperature increase are given for the different versions of the same modelling center. It can be seen that there are again substantial differences between the different versions. The change in the South - North and West - East gradients in $1xCO_2$ (control) and $2xCO_2$ (greenhouse) cases is shown for the investigated area in Table 5. These gradients were computed as a simple difference between the outermost gridpoints in the processed region. For almost all cases S - N gradient is smaller for the $2xCO_2$ run. It means that models give larger warming in the North than in the South of the region.

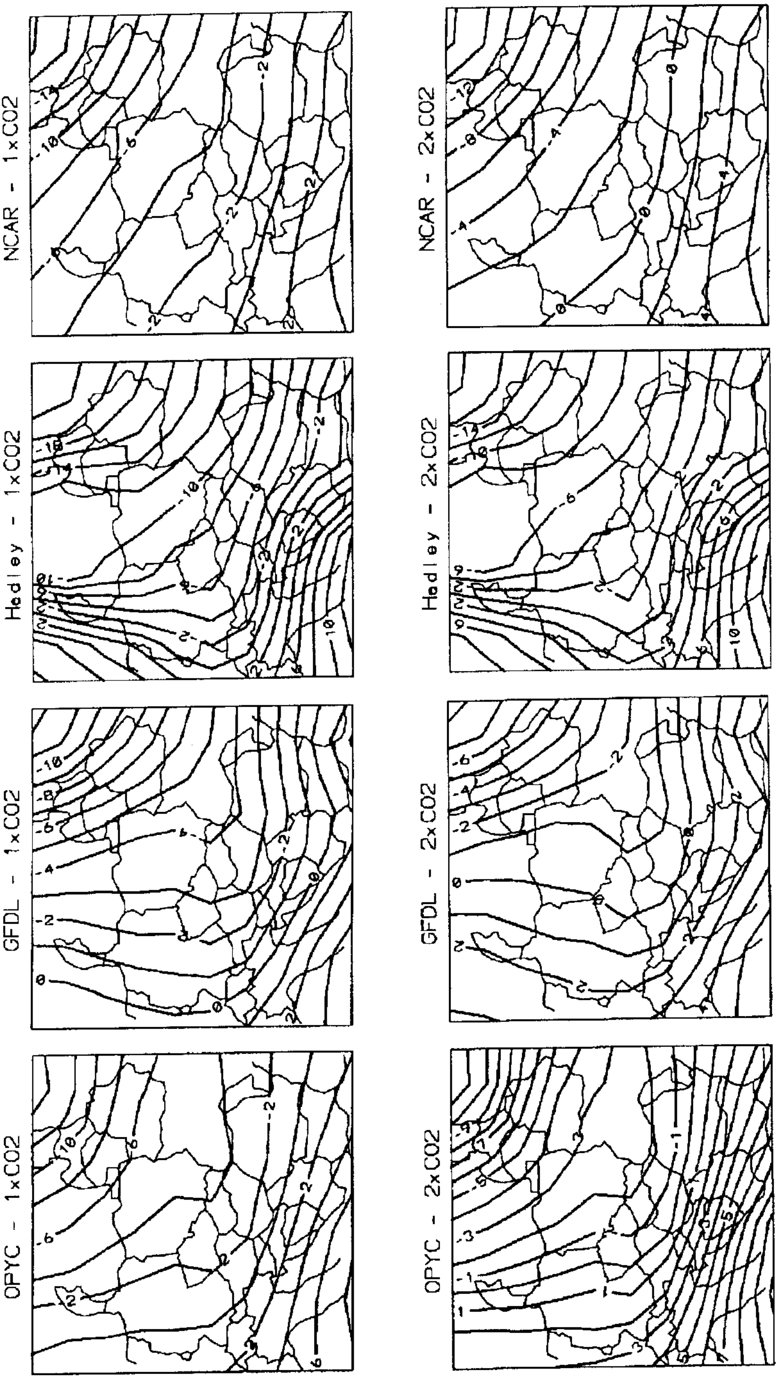

Fig. 4a. Comparison of $1xCO_2$ run (upper part) and $2xCO_2$ run (lower part) for four transient models in Central Europe - winter

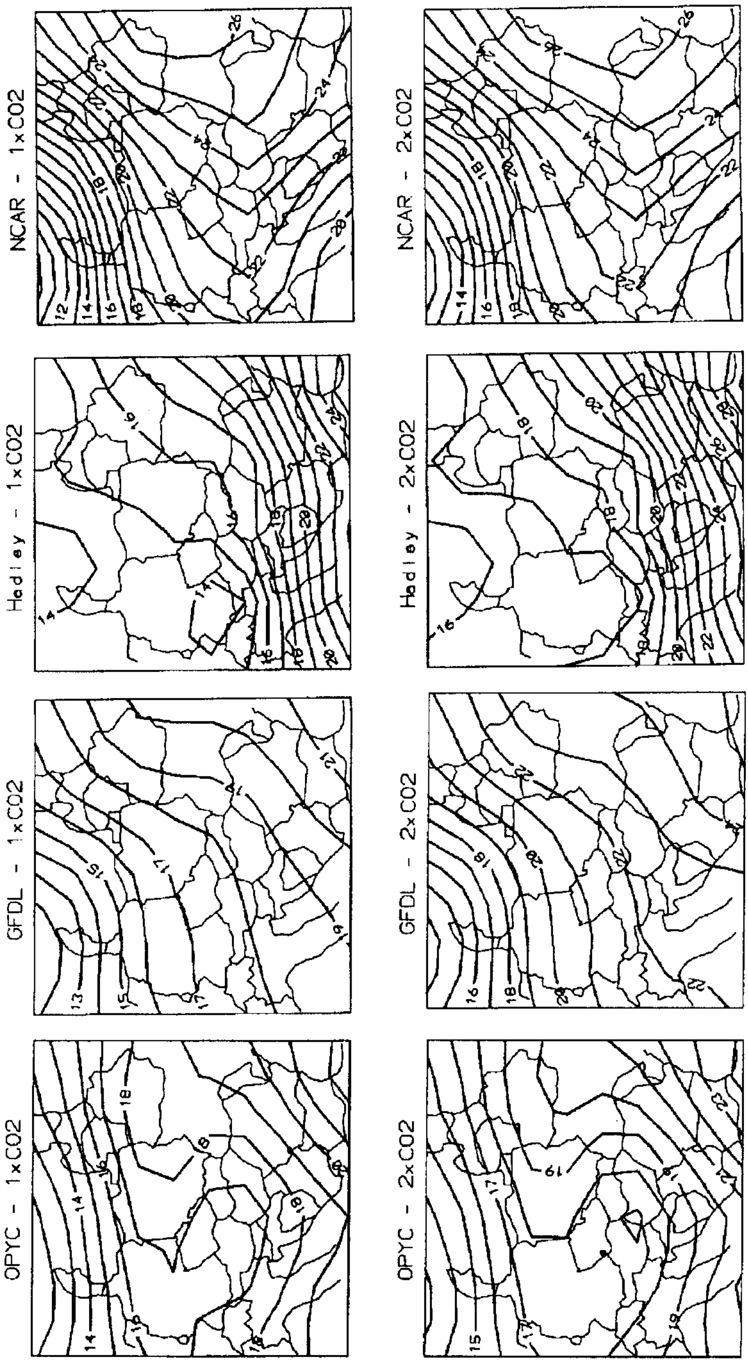

Fig. 4b. Comparison of 1xCO_2 run (upper part) and 2xCO_2 run (lower part) for four transient models in Central Europe - summer

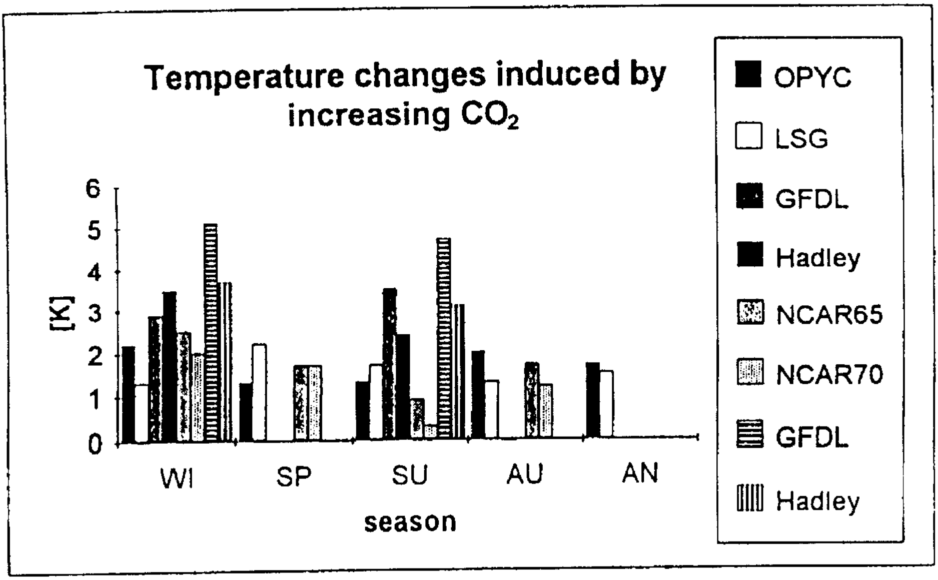

Fig. 5. Temperature changes induced by increasing CO_2 according several models for Central Europe

		South - North		West - East	
		control	greenhouse	control	greenhouse
WI	OPYC	14.2	13.0	5.2	5.7
	GFDL	5.6	4.5	4.2	3.6
	Hadley	23.7	22.1	11.4	7.0
	NCAR	12.6	10.6	3.4	2.6
SP	OPYC	10.8	10.1	6.3	2.1
	NCAR	9.1	7.6	-0.1	-0.3
SU	OPYC	6.4	5.9	-1.3	-2.1
	GFDL	5.6	6.6	-2.1	-1.7
	Hadley	9.1	8.9	-4.2	-4.7
	NCAR	6.0	5.8	-4.2	-1.1
AU	OPYC	9.9	8.8	2.5	1.7
	NCAR	9.2	9.0	-0.3	0.8
AN	OPYC	10.3	9.5	2.1	1.8
	LSG	10.5	9.6	0.3	-0.2

Table 5. Average temperature gradients for Central Europe in K for all seasons and annual values

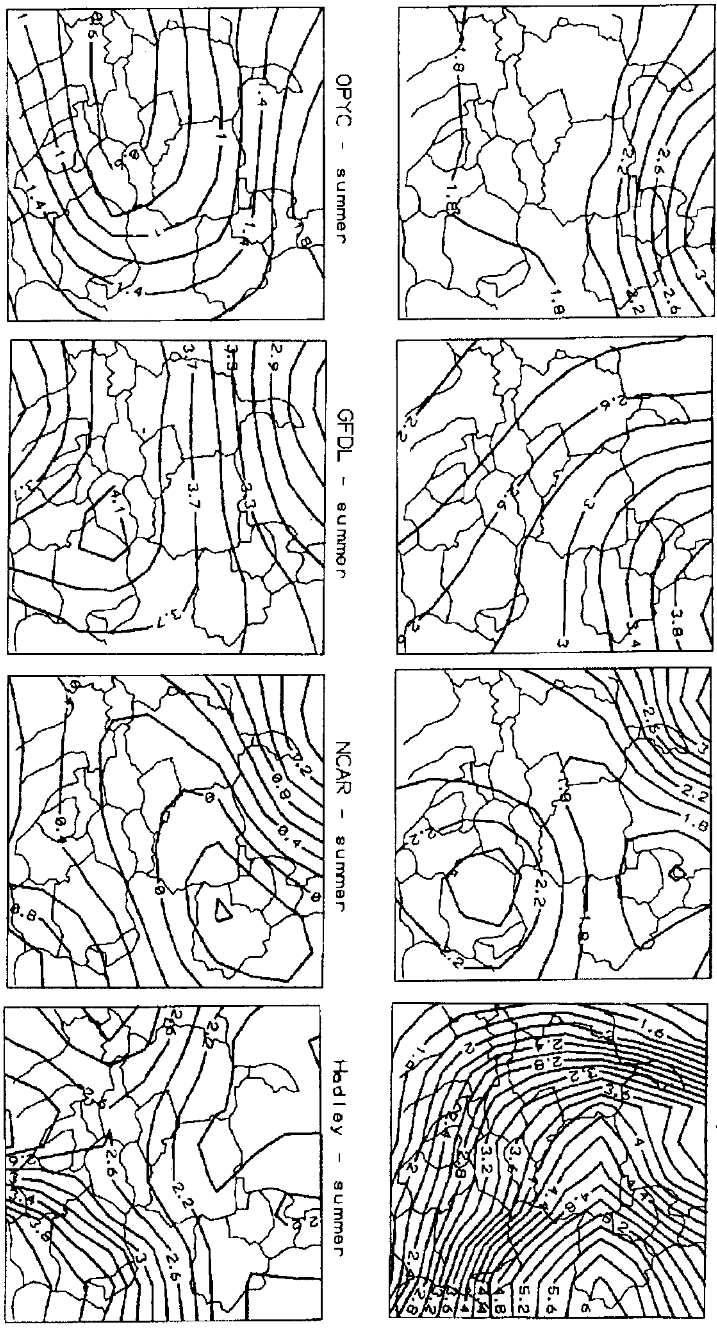

Fig. 6. Spatial distribution of temperature changes induced by doubling CO_2 for four transient models for Central Europe; winter (upper part), summer (lower part)

Spatial distribution of temperature changes caused by CO_2 doubling over Central Europe for 4 transient GCMs is shown on Fig. 6. Spatial patterns of climate change are very different from model to model both for winter and summer. Except GFDL all models give higher rise in temperature for winter season. High gradient for Hadley model in winter is caused by a used temperature characteristic in this model.

CONCLUSIONS

It can be said that the method of interpolation of observed data influences the results of comparison. Spatial temperature patterns remain the same, one must therefore prefer patterns against the absolute values. Model output patterns from control runs are very similar to the observed ones with a few exceptions, especially for summer, but RMS (mainly systematic) errors are rather considerable in most models and seasons. Spatial patterns of temperature fields remain very similar after transient CO_2 doubling, whereas the S-N gradients are smaller. The greenhouse runs in the available experiments indicate a larger increase of temperature in winter than in summer. Spatial patterns are well reproduced by OPYC model from DKRZ for all seasons except summer when Hadley equilibrium model has the best correlation with the observation data. Each model has some problems to reproduce absolute values measured by RMS error. The lowest differences are for LSG model in spring and annual values, for Hadley equilibrium model in summer and for OPYC model in autumn.

As was mentioned e.g. Grotch and MacCracken (1991), gridpoint values of temperature changes can not be directly used as a regional scenarios especially because of coarse horizontal resolution. Suitability evaluation of GCMs for regional scenario construction should be based at least on monthly values. From monthly values one can judge on an ability of the GCM to simulate not only spatial patterns but also temporal distribution during the year. On regional scales there are still significant errors due to short-comings of the models, e. g. spatial resolution and simplifications in the descriptions of the physical and dynamical processes.

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Supplement 1.

Methods for interpolation of observed data and their comparison

1. Continental approach
Multiple regression and construction of hyperplane

$T(\varphi,\lambda,z) = T_o + a_1\varphi + a_2\lambda + a_3 z$ from 109 stations

$T(\varphi_{ij},\lambda_{ij},z_{ij}) = T_o + a_1\varphi_{ij} + a_2\lambda_{ij} + a_3 z_{ij}$ to 21 gridpoints

2. Local approach
Unweighted areal averages for each rectagulae around the gridpoints corrected by the altitude

$$T(\varphi_{ij}, \lambda_{ij}, z_{ij}) = \frac{1}{L}\sum_{u=1}^{L} T(\varphi_u \lambda_u z_u) \frac{z_{ij}}{\frac{1}{L}\sum_{u=1}^{L} z_{ij}}$$

Explanations: φ - latitude, λ - longitude, z - height above sea level, a_1,a_2,a_3 - regression coefficients, T - temperature, L - number of stations in rectangulae, u, i, j - indices for individual station

Comparison between continental and local approach

Averages [K]	WI	SP	SU	AU	AN
Continental	-0.1	7.5	16.8	8.0	7.9
Local	0.8	9.1	18.7	9.8	9.6

Pattern correlation	WI	SP	SU	AU	AN
Continental vs. Local	.88	.86	.82	.83	.85