Analysis of Uncertainty in Large Scale Climate Change Projections over Europe

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R e L o C l i m

1 Introduction

Quantifying and reducing the uncertainties in climate change projections is currently one of the biggest issues in climate research. The major sources of uncertainty in global climate change projections are:

- **internal variability** of the climate sysetem
- **emission scenario uncertainty**
- **model uncertainty** (Model formulation, imperfect understanding)

Previous studies dealing with uncertainties in climate change signals (CCSs) mainly focus on 2 m temperature and precipitation. Here not only surface but also upper air parameters are analyzed to address the following topics:

- deriving a detailed overview of the magnitude and uncertainty of CCSs over Europe
- analyzing the vertical distribution of CCSs
- quantifying the sources of uncertainty in CCSs

The results of this study aim to aid the application of global climate scenarios as boundary conditions for regional climate change impact studies in Europe.

2 Data and Methods

2a) Domains and Data

The focus area of this study is central **Europe** (see Fig.1). Nine parameters (described in Tab.1) from 84 runs (23 different GCMs) of the Climate Model Intercomparison Project 3 (**CMIP3**) are considered. Only one CMIP3-GCM (ECHO-G) was disregarded because of missing data.

For the CCSs calculation data of the B1, A1B, and A2 emission scenario runs and for the reference period 20C3M data are used.

2b) Climate Change Signals (CCSs)

For the CCS calculation all perturbed initial condition runs of one GCM are averaged (but not for the uncertainty analysis) and shown in box-whisker plots. The CCS are calculated for two different time periods:

S1: 2021—2050 minus 1971—2000
S2: 2071—2100 minus 1971—2000

2c) Uncertainty Estimation

The uncertainty estimation was done with a method described in DEQUE et al. (2007). The basic idea is to use the analysis of variance (**ANOVA**) method to split the total variance into sums according to the uncertainty components. However, to use the ANOVA all GCMs must have simulations in all three emission scenarios and overall nine perturbed initial condition runs. Therefore, a missing data reconstruction method is used to estimate the CCSs of the not missing GCM simulations.

3 Results & Discussion

3a) CCS Analysis

Positive CCSs are projected by all simulations in all seasons for **air temperature** (Fig.2a, and 3 Ia & Ib), **geopotential height**, and **specific humidity** . The CCSs of those three parameters are increasing with altitude in the Troposphere (Fig 2b, 2c). The increase in specific humidity is in good agreement with temperature increase following the Clausius Clapeyron equation.

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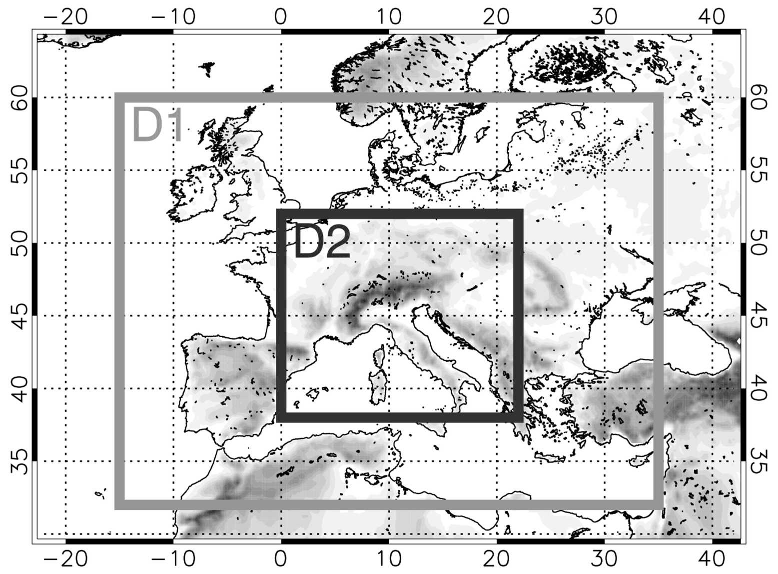

Fig. 1: The investigated domains D1 (32°N to 60°N and 15°Wto 35°E) and D2 (38°N to 52°N and 0°E to 22°E).

Tab. 1: Nine parameters which are essential for the dynamics in RCMs and/or well observed are considered. The values of 2m air temperature, precipitation flux and air pressure are given on the ground level while the other parameters are given at four pressure levels.

	Variable	Unit	Level
tas	2 m air temperature	K	ground
pr	precipitation	kg/m²s	
psl	sea level pressure	Pa	
ta	air temperature	K	850, 700, 500, 300 hPa
hus	specific humidity	g/kg	
zg	geopotential height	m	
ua	eastward wind	m/s	
va	northward wind	m/s	
wap	lagrangian tendency of air pressure	Pa/s	

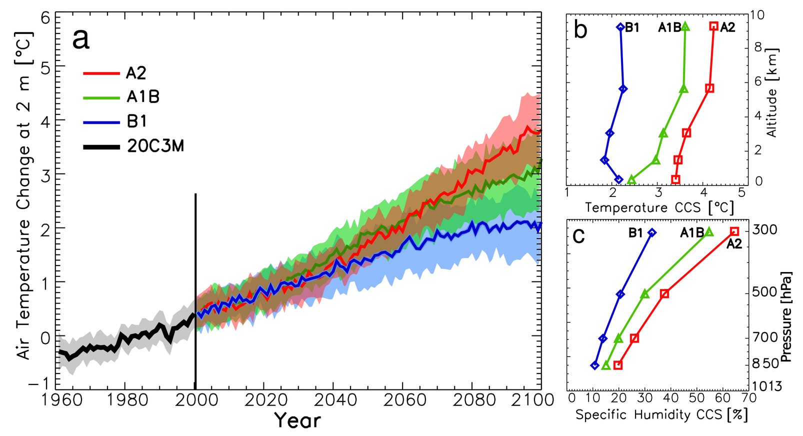

Fig. 2: Panel a depicts the change of 2 m temperature (TAS) relative to 1971–2000. Thick lines show the multi-model mean, shadings the standard deviation of the ensemble. Panel b and c show the vertical structure of the CCS for the S2 period (end of 21st century) for temperature (TA) and specific humidity (HUS).

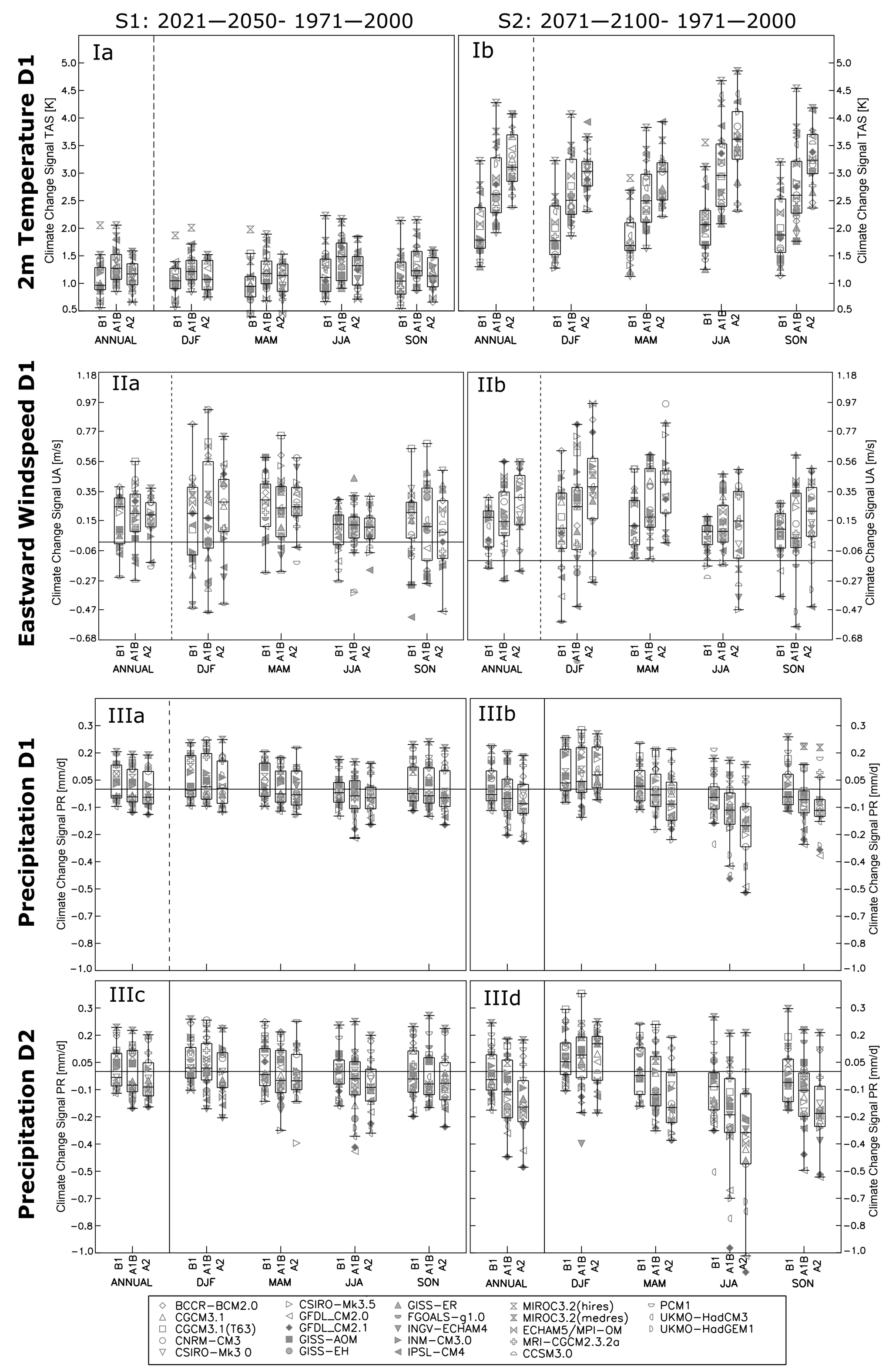

Fig. 3: Box whisker plots for the CCSs of 2 m temperature (TAS), eastward wind speed at 500 hPa (UA), and precipitation (PR). Panels a display always the CCSs for the mid 21st century (period S1) while panel b shows the end of the century (period S2) for the large domain D1. For precipitation also the CCSs on the small domain D2 are depicted (panel IIIc and IIId on the bottom). The boxes represent the interquartile (Q25 to Q75) distance. Displayed are the CCSs for all emission scenarios and models on annual and seasonal basis. CCSs of single GCM can be identified by the symbol as listed at the bottom of the figure.

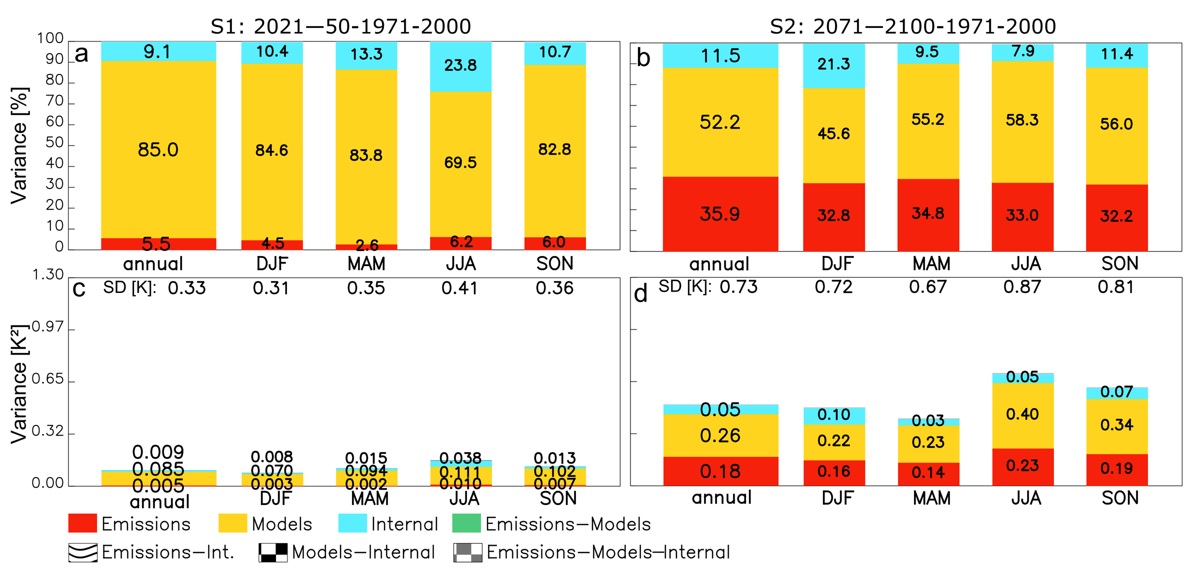

Fig. 4: Uncertainty components of the 2m temperature (TAS) CCS for the mid 21st century (S1, panels a and c) and for the end of the century (S2, panels b and d). Panel a and b show the fractional contribution of each uncertainty component, while panels c and d display the absolute values of variance. In panel c and d also the total standard deviation (SD) is quoted above the bars.

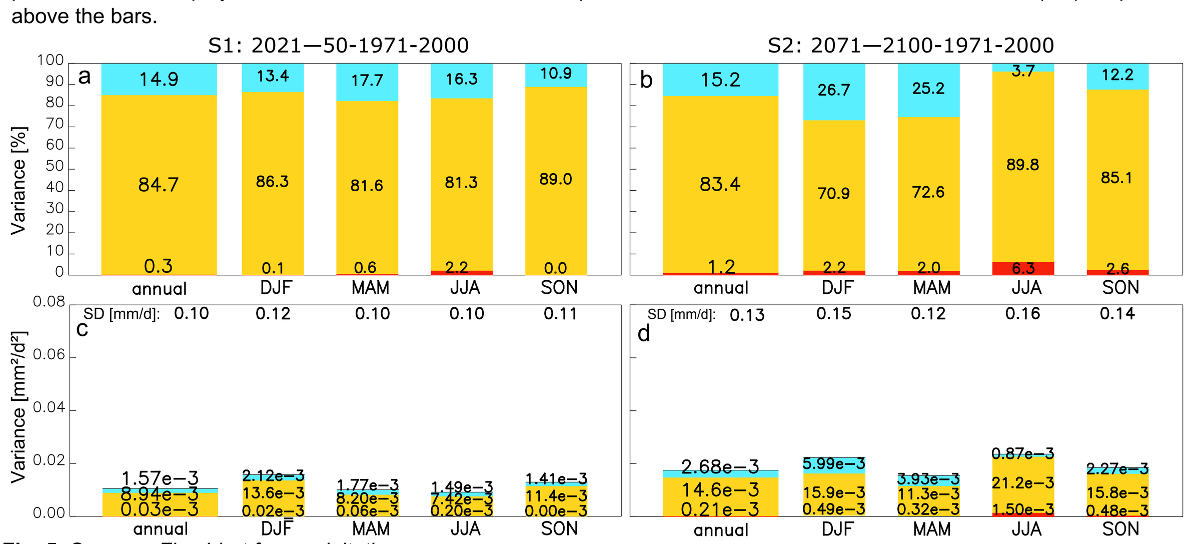

Fig. 5: Same as Fig. 4 but for precipitation.

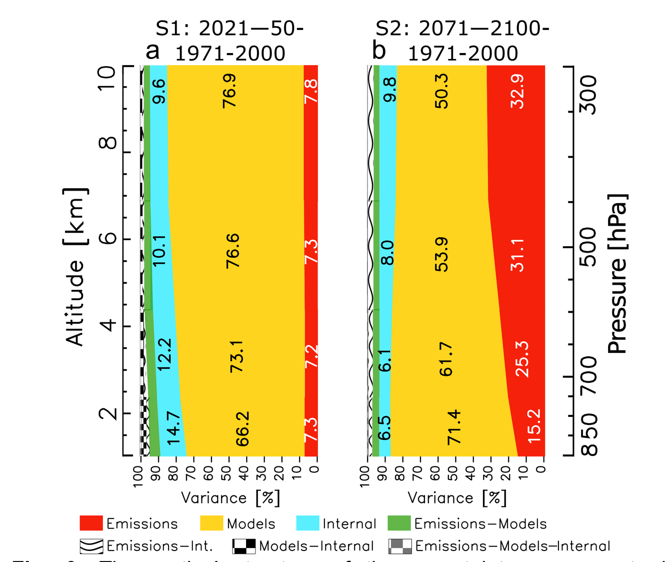

Fig. 6: The vertical structure of the uncertainty components in geopotential height (ZG) change for the mid 21st century (S1, panel a) and the end of the century (S2, panel b). The quoted values refer to the uncertainty components at pressure levels 850 hPa, 700 hPa, 500 hPa, and 300 hPa.

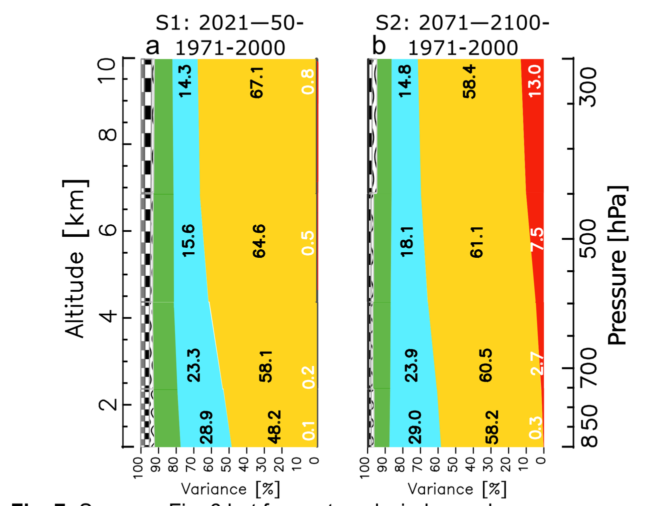

Fig. 7: Same as Fig. 6 but for eastward wind speed.

CCSs of the **eastward wind** velocity are mainly positive (Fig.3 IIa & IIb). CCSs of **sea level pressure** and **northward wind** component vary with season. Sea level pressure, eastward and northward wind components are increasing in winter which could be related to a strengthening of the North Atlantic Oscillation. **Precipitation** shows a tendency to decrease in summer and increase in winter (Fig.3 IIIa & IIIb) with higher amplitudes in the small domain (Fig.3 IIIc & IIId) and a aplification at the end of the 21th century.

3b) Uncertainty Analysis

Temperature (Fig.4 c & d), **precipitation** (Fig.5 c & d), and **specific humidity** are most uncertain in summer (weak synoptic scale forcing, smaller scale processes). Parameters which are stronger related to larger scale processes, like **wind speed**, **sea level pressure** and **geopotential height**, have their uncertainty maximum in winter.

Model uncertainty contributes the major fraction to total uncertainty (between 50 % and 85 %) particularly in the first half of the 21th century (Fig. 4-7). **Emission scenario uncertainty** is small (below 10 %) in the first half and higher only for temperature, specific humidity, and geopotential height in the second half of the century (Fig. 4 & 6). **Internal uncertainty** is normally below 20 %. The, uncertainty components of geopotential hight and eastward wind speed show a height dependency (Fig. 6 and 7).

The absolute uncertainty is higher in the **small domain** D2 for all parameters, seasons, and periods. However, the relative contributions of the uncertainty components or the seasonal variation of absolute variance stays similar.

4 Conclusions

- 2m temperature (T2M), geopotential hight (ZG), and specific humidity (HUS) are projected to increase by all GCMs.
- For all other parameters, GCMs show different signs of climate change signals (CCSs) and partly different directions for different seasons.
- **GCM formulation** contributes the largest part to total uncertainty (50-80 %) especially in the first half of the 21st century.
- **Emission scenario** uncertainty is negligible until 2050 and gets only important for T2M, ZG, and HUS until 2100.
- **Internal uncertainty** is small (Ø 12 %) for 30 year mean CCSs. However, internal variability is expected to be more dominant when looking at shorter time periods.
- Studies focusing on **downscaling, regional climate change**, and regional climate change impacts in Europe should be based on a carefully selected set of GCMs in order to avoid undersampling uncertainty. It is by far more relevant to reasonably capture model uncertainty than emission scenario uncertainty. This is particularly true for the first half of the 21th century and particularly important for more uncertain parameters like precipitation.

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