Quantifying uncertainties in future projections using a perturbed land surface parameter experiment

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Thanks to: Dave Lawrence, Ben Sanderson, Keith Oleson and Jerry Meehl

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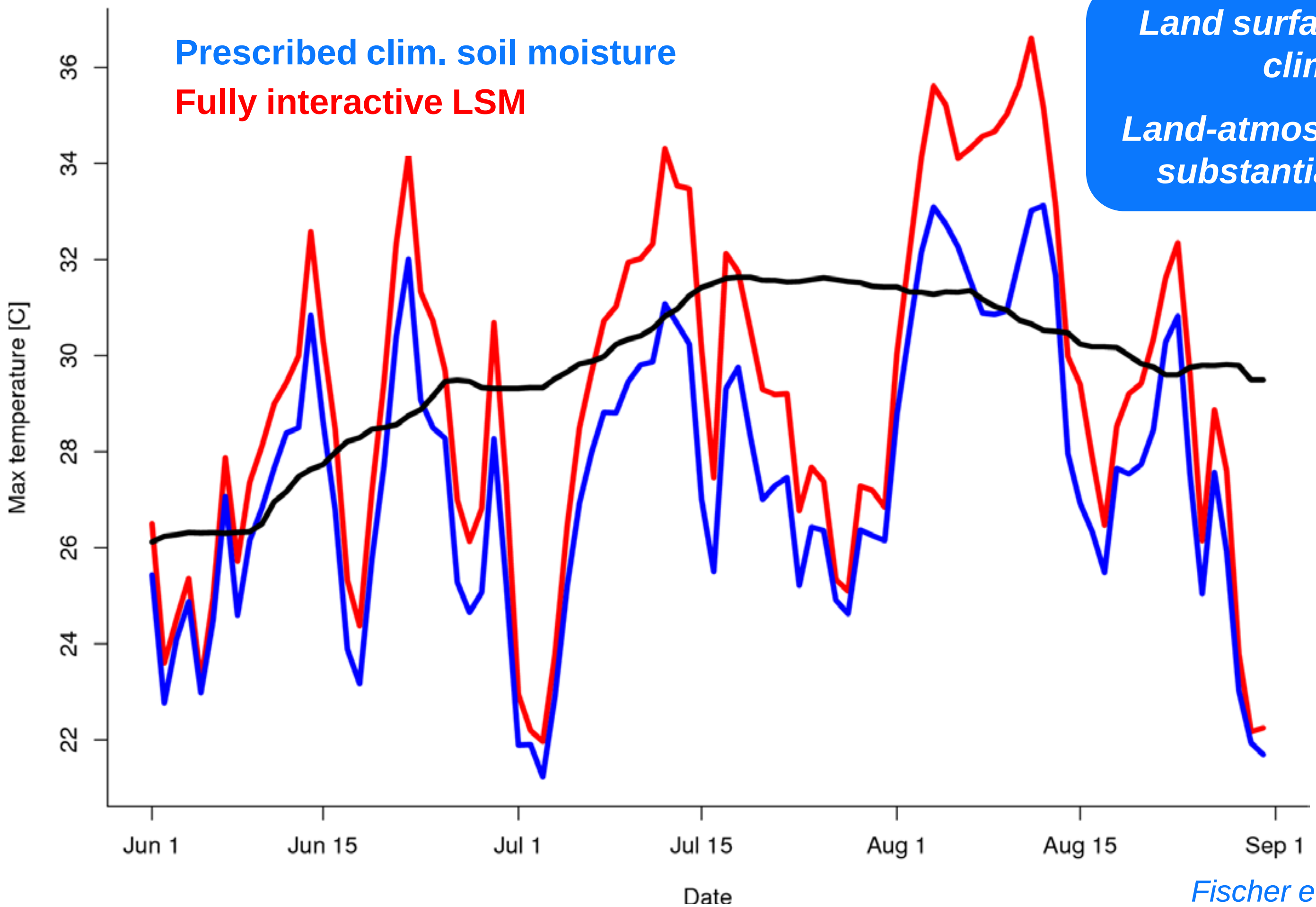
Motivation (2003 European heat wave)



Land surface feedbacks amplify climate extremes

Land-atmosphere coupling differs substantially between models

Fischer et al. 2007a, J. Climate
Fischer et al. 2007b, GRL

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Objectives

- Quantifying uncertainties in future projections of extreme events due to parameter uncertainties in the land-surface scheme

- Exploring land-atmosphere coupling strength in simulations with different land surface parameter sets

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Experimental setup

Model setup (motivated by climateprediction.net and QUMP)

- CAM/CLM 3.5 with slab ocean
- 30-year simulations with 1xCO_2 and 2xCO_2
- different combinations of perturbed parameters (may interact non-linearly)

- 5 parameters with a total experiment of 108 ensemble members
  -> 8100 model years of daily data!

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Experimental setup

Parameter perturbations

- Selected land surface parameters are poorly constrained
- Perturbations should be justifiable and if possible based on literature and/or observational studies
- Parameters are tested using offline CLM version forced with observed atmosphere

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Selected parameters

- Vegetation albedo: leaf albedo perturbed by +/- 20% for all PFTs
- Snow albedo: empirical constant in aging function -> faster and slower decrease in snow albedo
- Momentum roughness length (doubled, corresponds roughly to values used in the ECMWF LSM Tessel)
- Decay factor f in the calculation of subsurface runoff, which affects water table depth (moderate and strong increase of WT depth, based on Niu et al. 2005)
- Vcmax (see next slide)

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V_{cmax} (max. of carboxylation)

	SLA std	max	CN_L std	max
NET temperate	0.010	0.0136	35.0	46.0
NET boreal	0.008	0.0116	40.0	51.0
NDT boreal	0.024	0.0282	25.0	30.6
BET tropical	0.012	0.0156	30.0	37.0
BET temperate	0.012	0.0156	30.0	37.0
BDT tropical	0.030	0.0410	25.0	30.4
BDT temperate	0.030	0.0410	25.0	30.4
BDT boreal	0.030	0.0410	25.0	30.4
BES temperate	0.012	0.0171	30.0	42.0
BDS temperate	0.030	0.0410	25.0	37.0
BDS boreal	0.030	0.0410	25.0	37.0
C_3 grass arctic	0.050	0.0660	25.0	33.6
C_3 grass	0.050	0.0660	25.0	33.6
C_4 grass	0.050	0.0660	25.0	33.6
Crop1	0.050	0.0660	25.0	33.6
Crop2	0.050	0.0660	25.0	33.6

V_{cmax}: maximum carboxylation capacity of Rubisco at 25°C, which controls photosynthesis and affects transpiration (Thornton et al. 2007)

$$V_{max} = \frac{1}{SLA \times CN_L} F_{LNR} \frac{1}{F_{NR}} a_R,$$

SLA: specific leaf area, ratio of leaf area to leaf mass

CN_L: leaf carbon:nitrogen ratio (gC gN^{-1})

Perturbations based on 1 standard deviation given in White et al. (2000)

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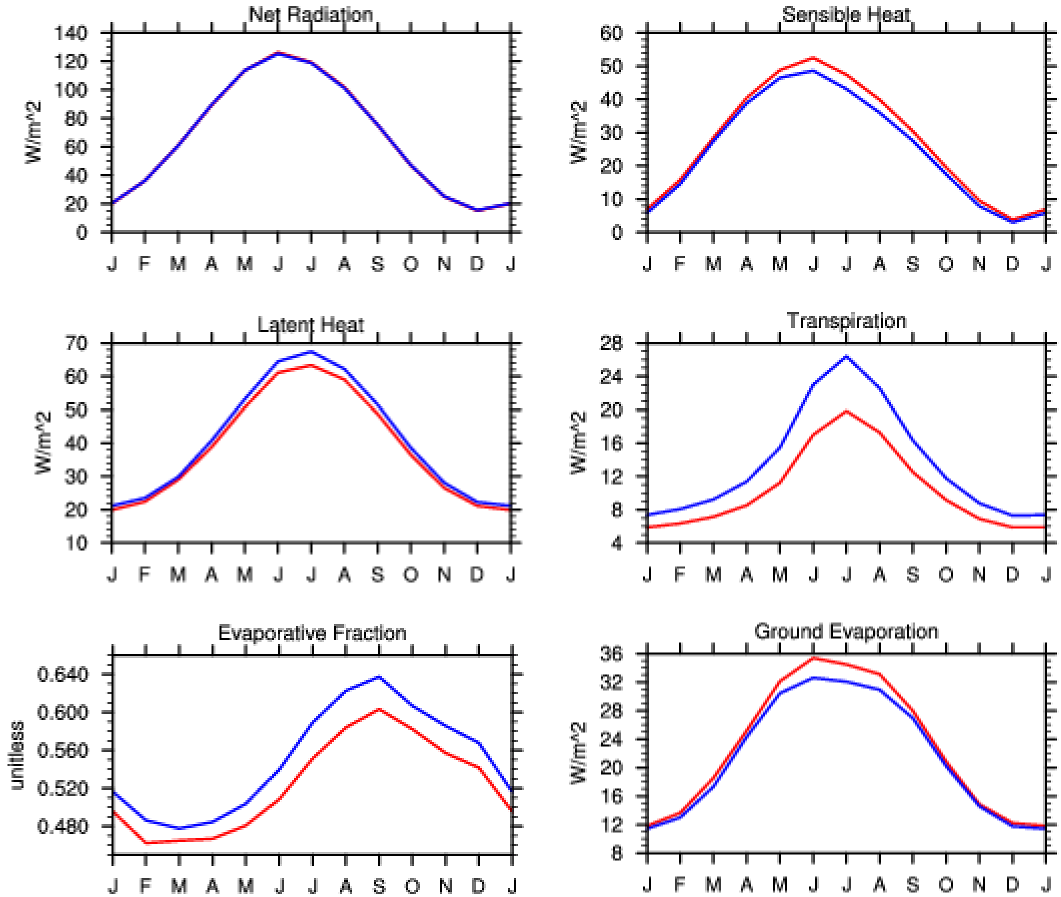
V_{cmax} (perturbed vs. CTL)

N. Hemisphere Land (EQ-90N,180W-180E)



Annual global energy budget:

latent heat	$-1.95 W/m^2$
transpiration	$-3.76 W/m^2$
ground evap.	$+1.70 W/m^2$
sensible heat	$+2.11 W/m^2$

Half of the reduction in transpiration is compensated by enhanced ground evaporation

Precipitation is substantially reduced over some regions

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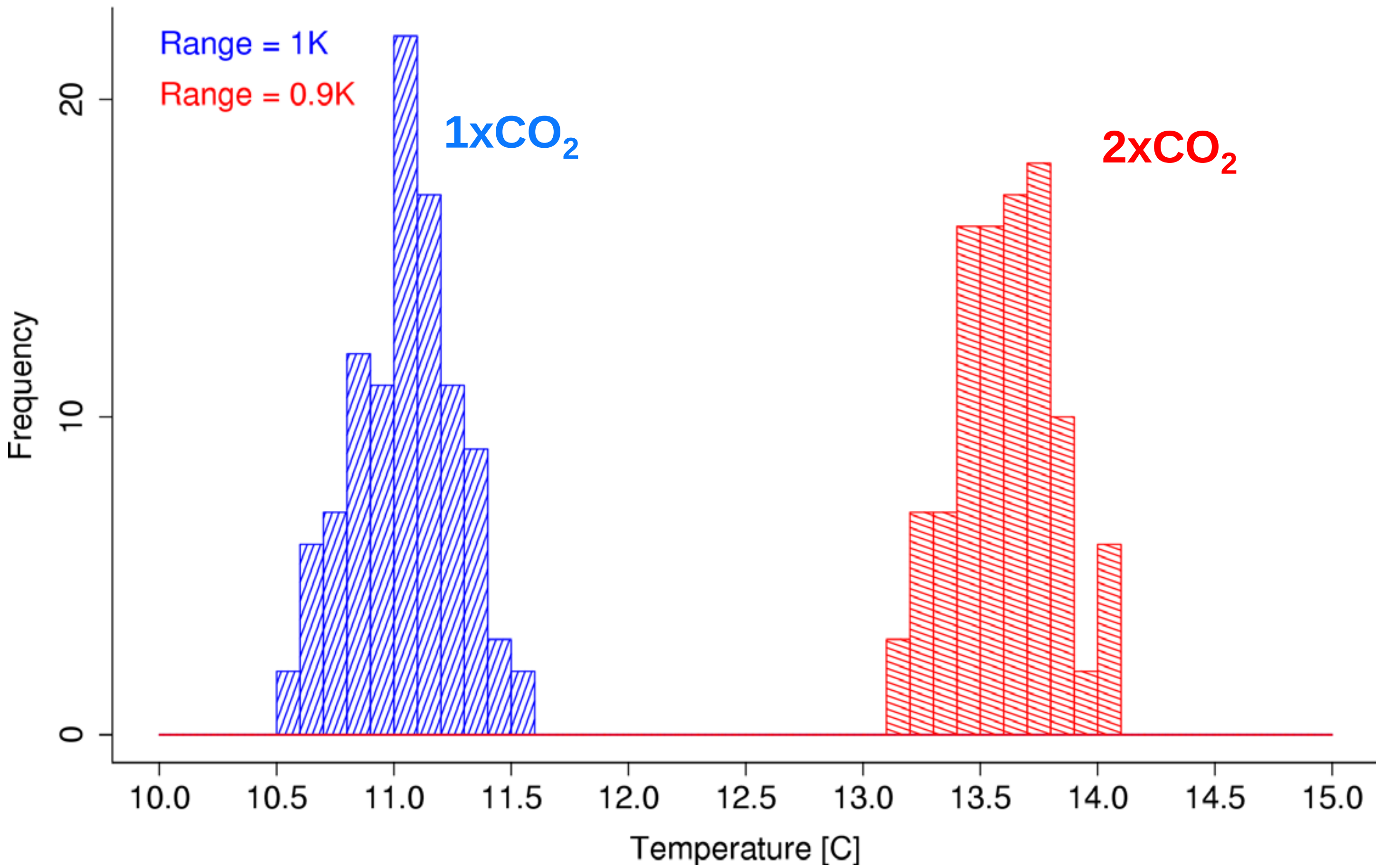
Global annual land temperature



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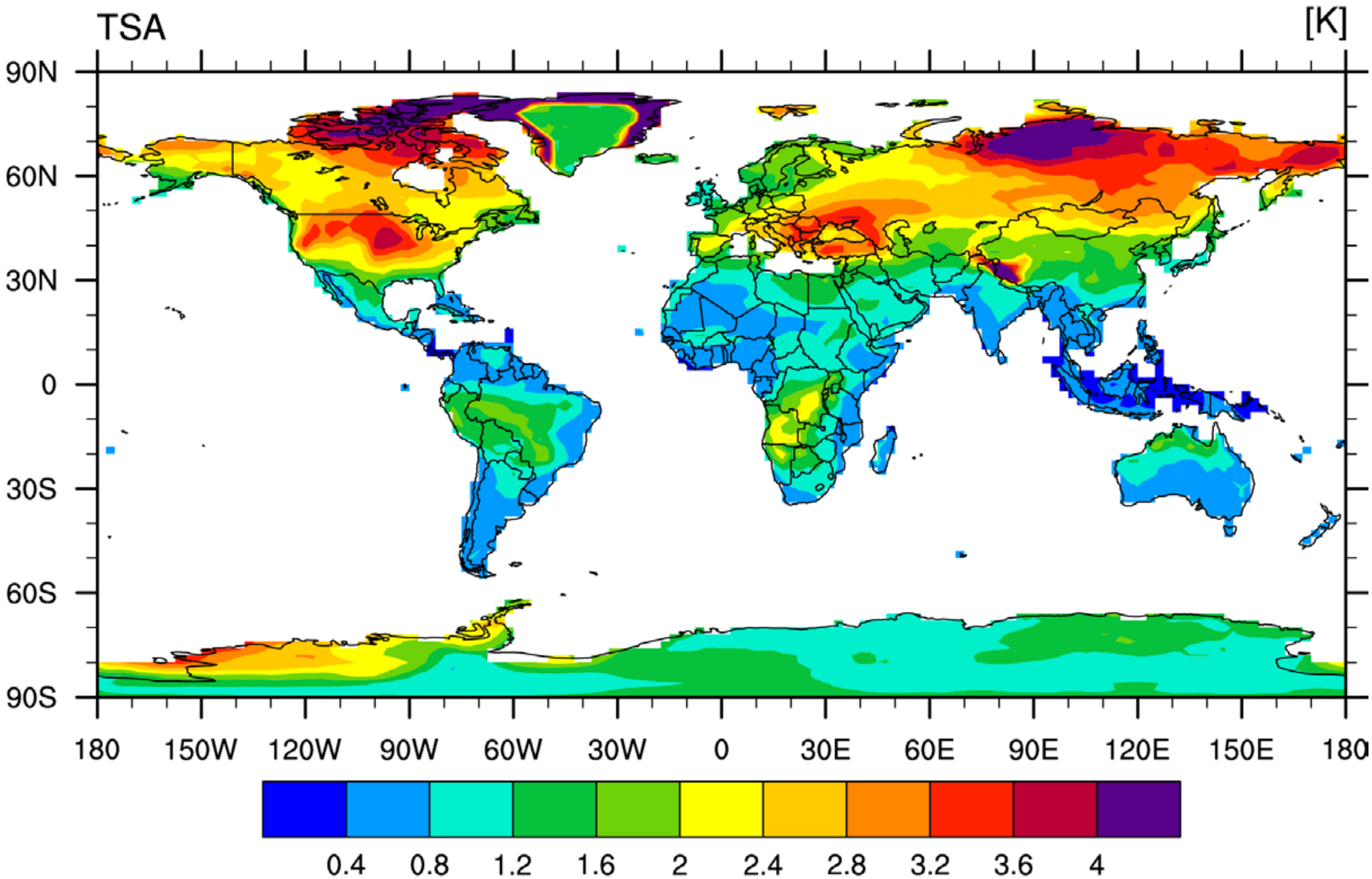
Range of JJA temperatures (1xCO_2)



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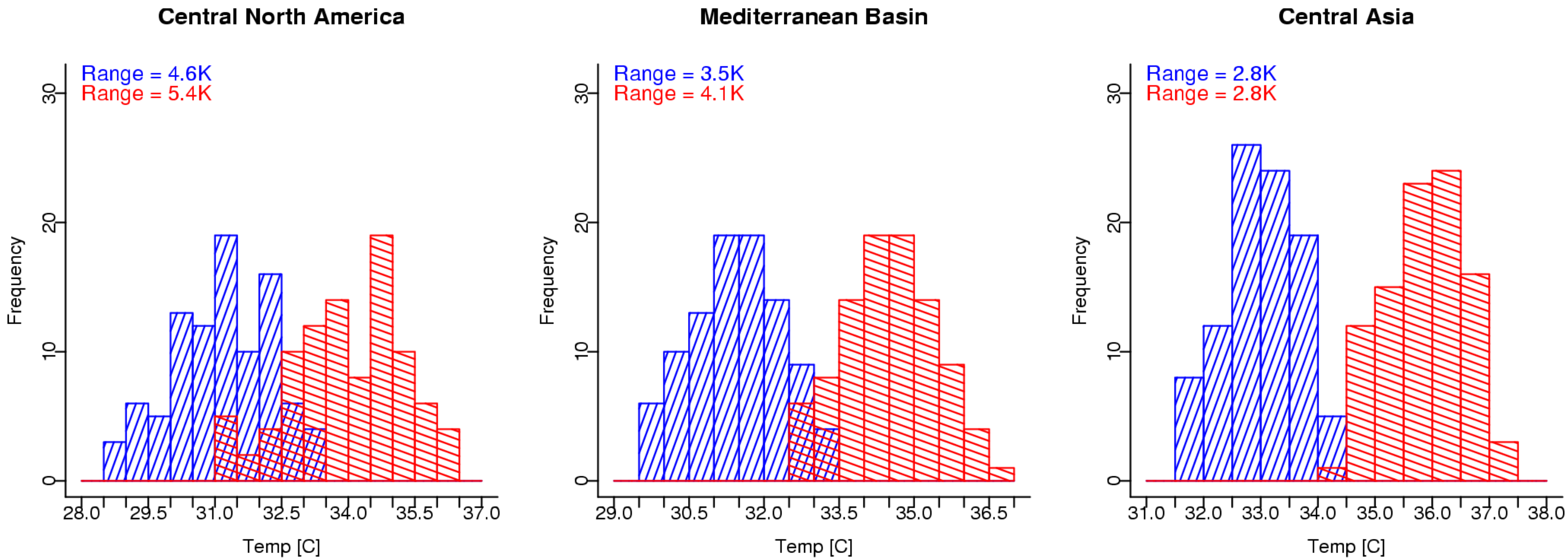
95th percentile of daily JJA temperatures



- ***Ensemble range is larger for temperature extremes***
- ***LSM parameters affect not only mean but also temperature variability***

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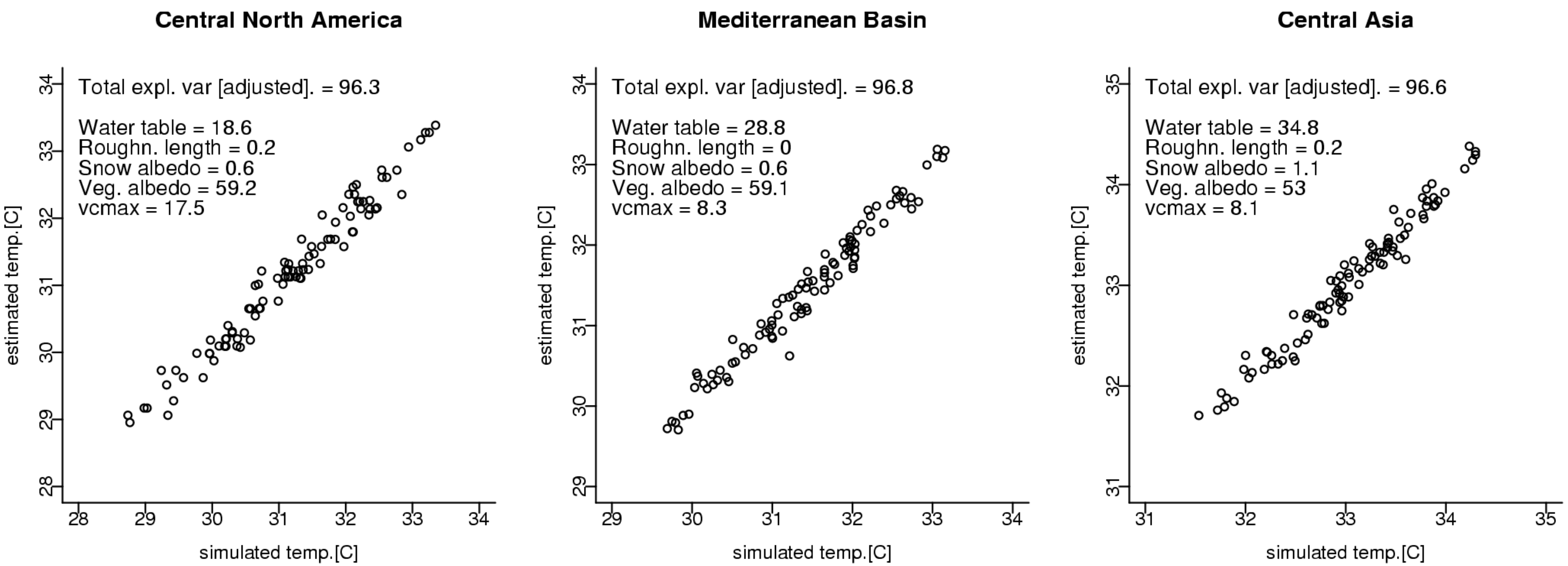
Role of parameters (explained variance)



- ***Current state can be remarkably well described by a multiple linear regression***
- ***Role of parameters differs regionally (generally veg. albedo dominant)***
- ***Approach fails to explain response to 2xCO_2 (highly nonlinear)***

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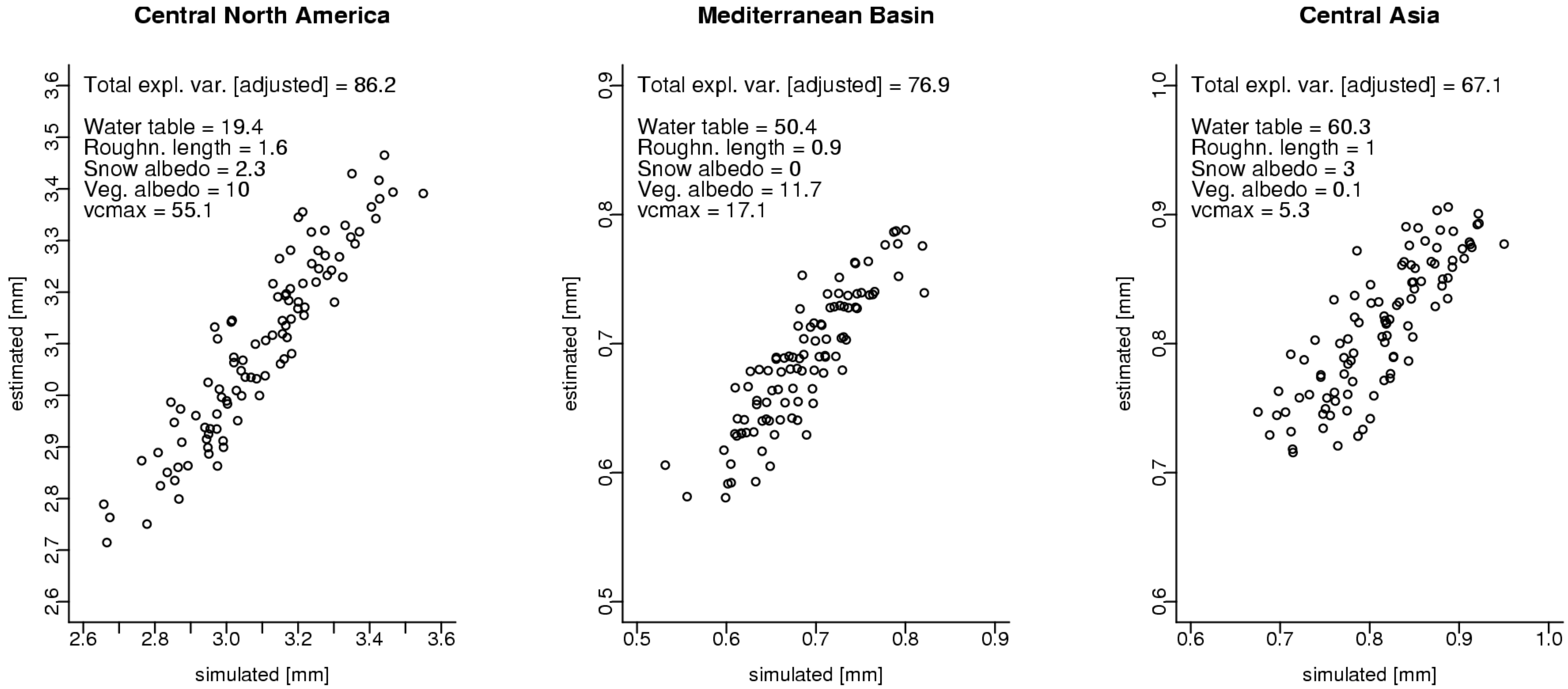
Role of parameters (JJA precipitation)



- ***Different parameters for precipitation than for temperature***
- ***Water table depth is dominant over arid regions, whereas Vcmax dominates over vegetated regions***

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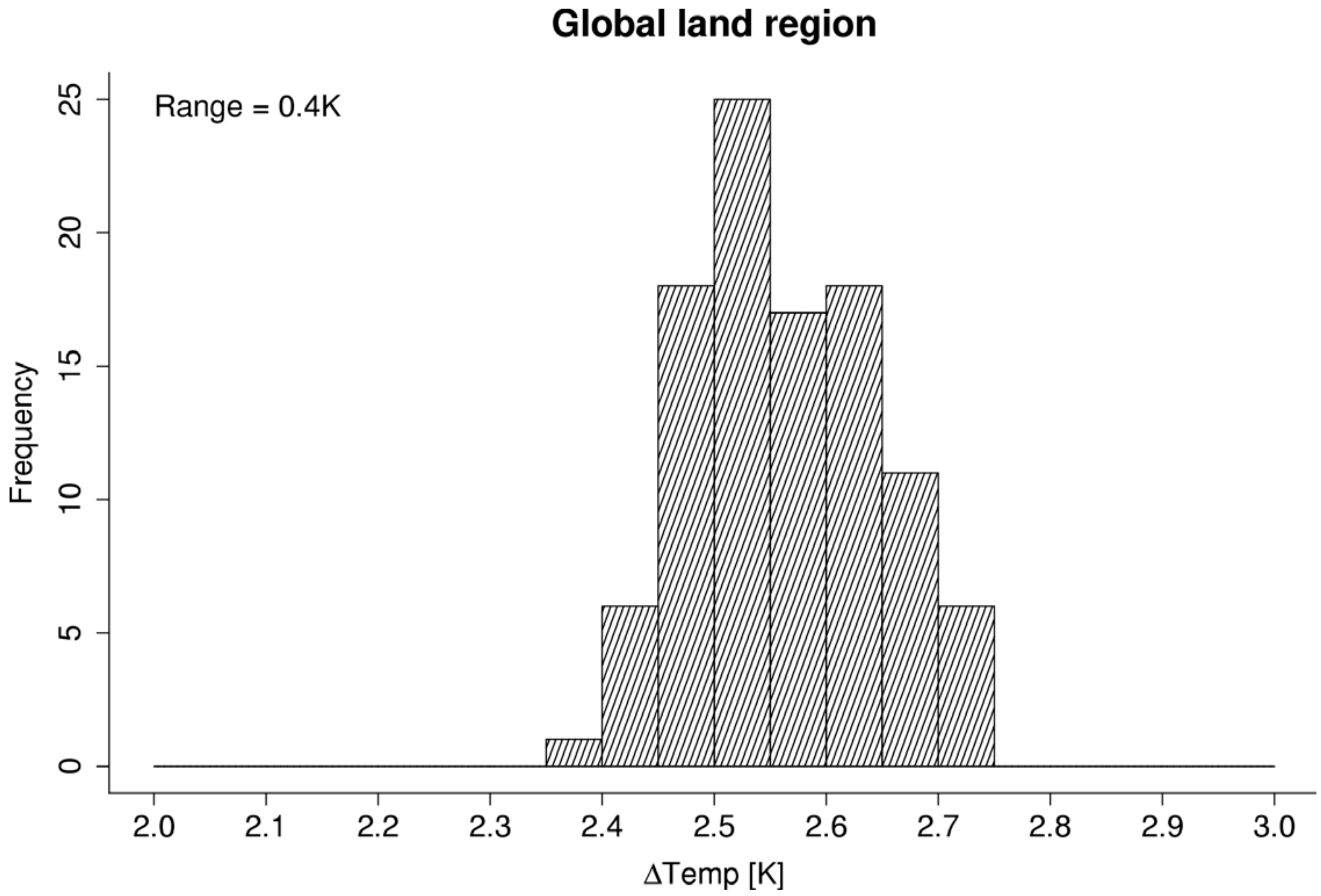
Land temperature response to $2xCO_2$



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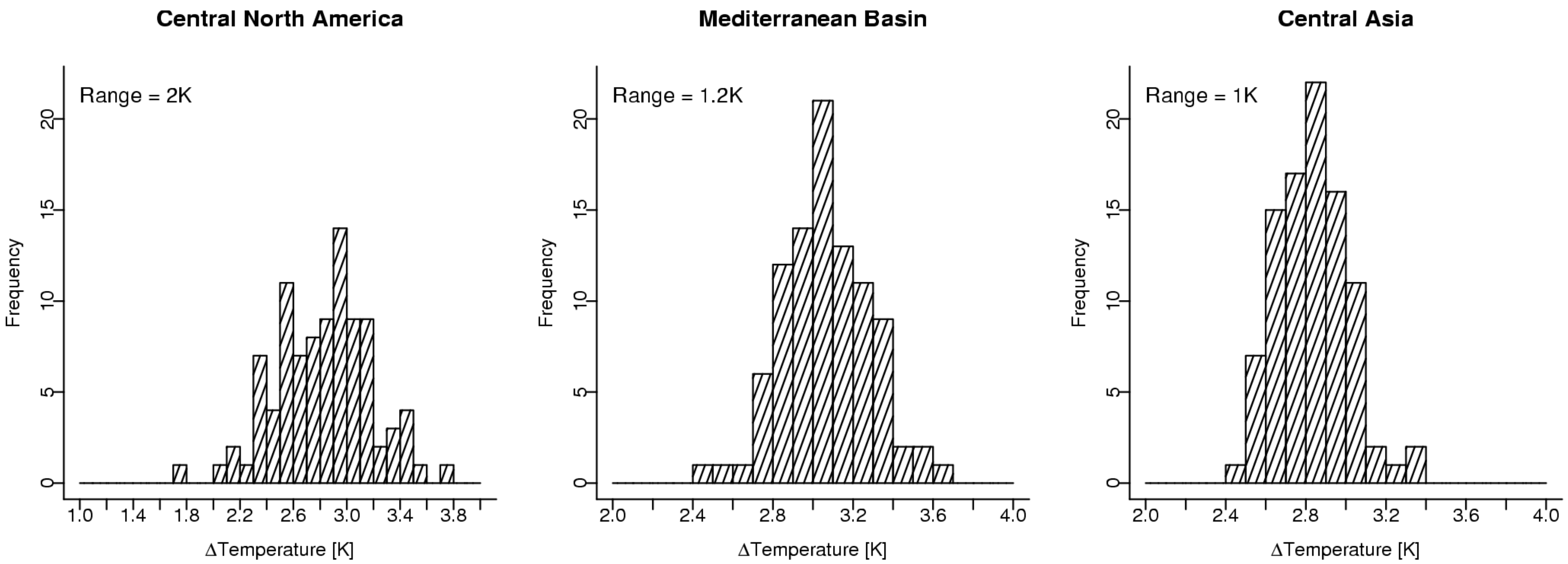
Regional change of 95th perc. (JJA)



- ***In contrast to current climate state, the response two 2xCO_2 depends on parameters in a highly non-linear way!***

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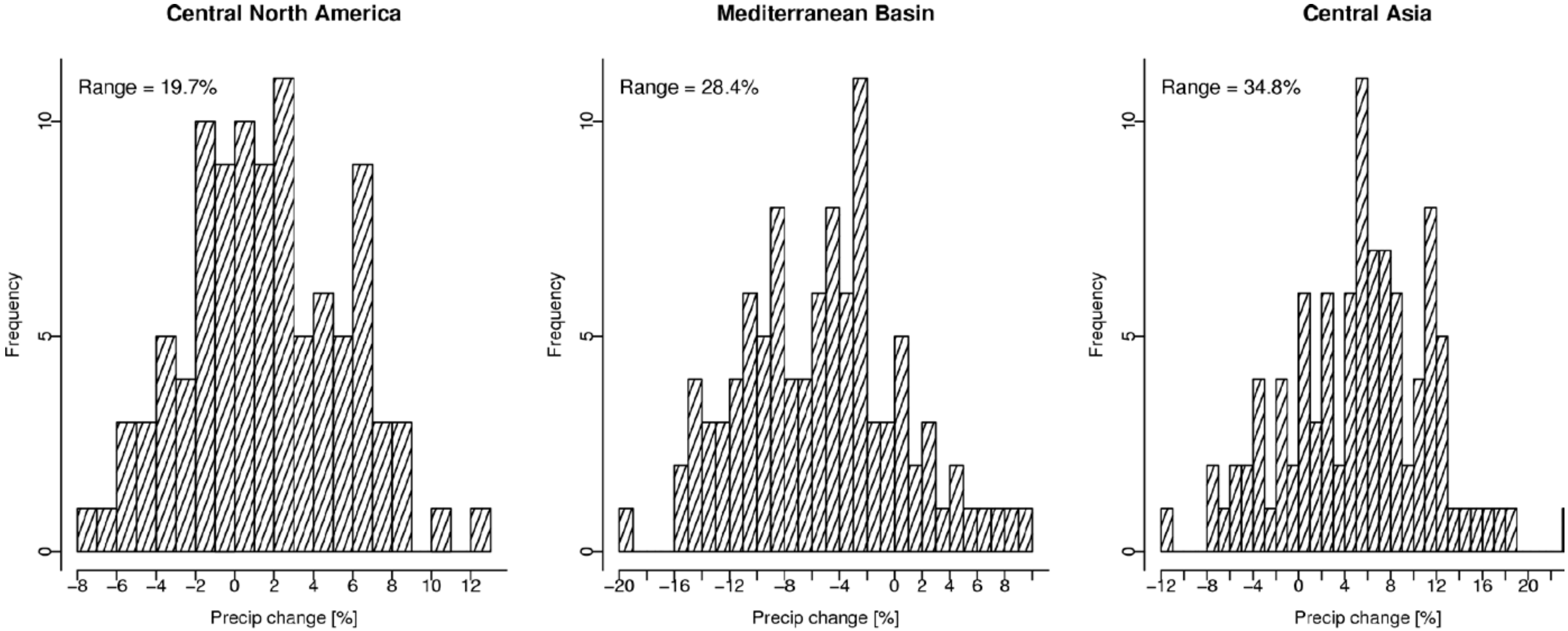
Regional JJA precipitation change



- ***Land parameters may even change the sign of the JJA precipitation response***
- ***CAM/CLM 3.5 seems to be generally wet and projects less droughts than other CMIP3 models***

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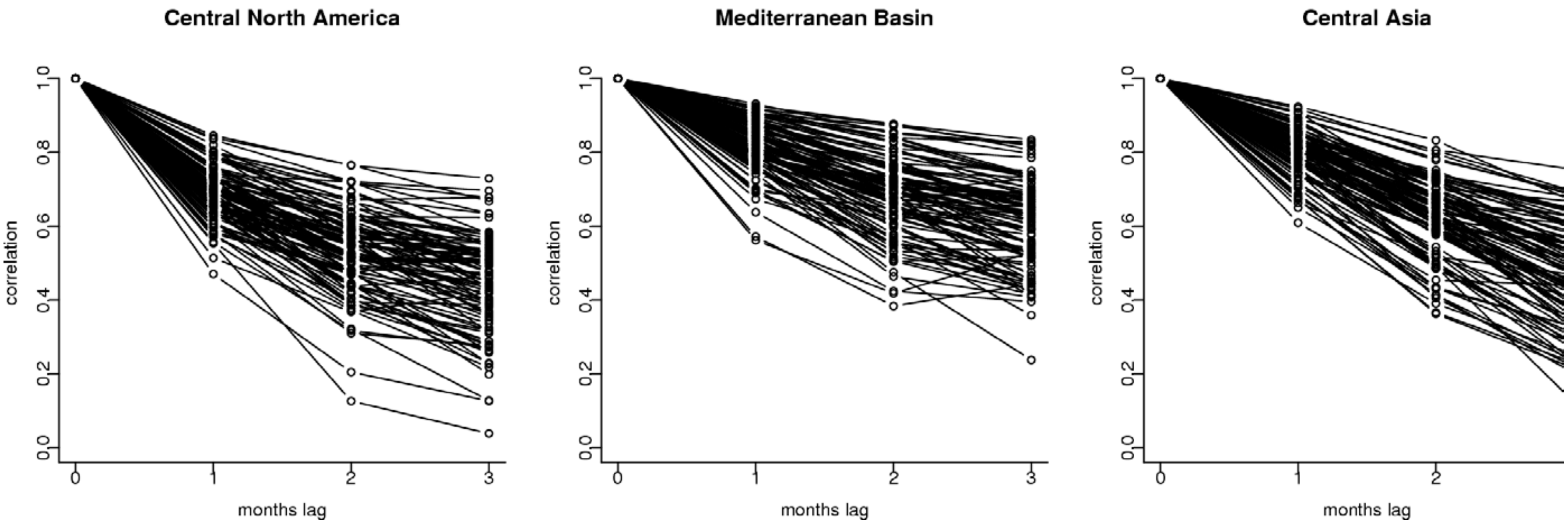
Soil moisture memory (lagged autocor.)



- ***Soil moisture memory calculated as a simple lagged autocorrelation differs substantially between ensemble members***

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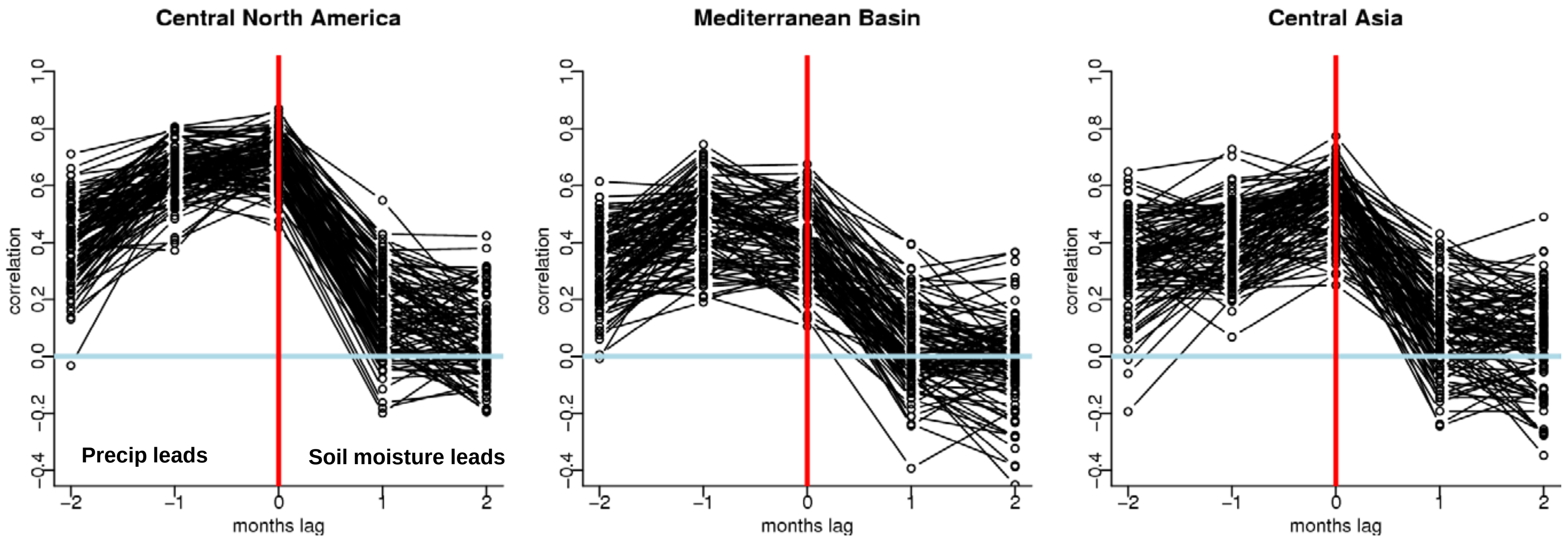
Soil moisture-precipitation coupling



- ***Very simple approach to determine soil moisture-precipitation coupling indicates large range of coupling strengths***

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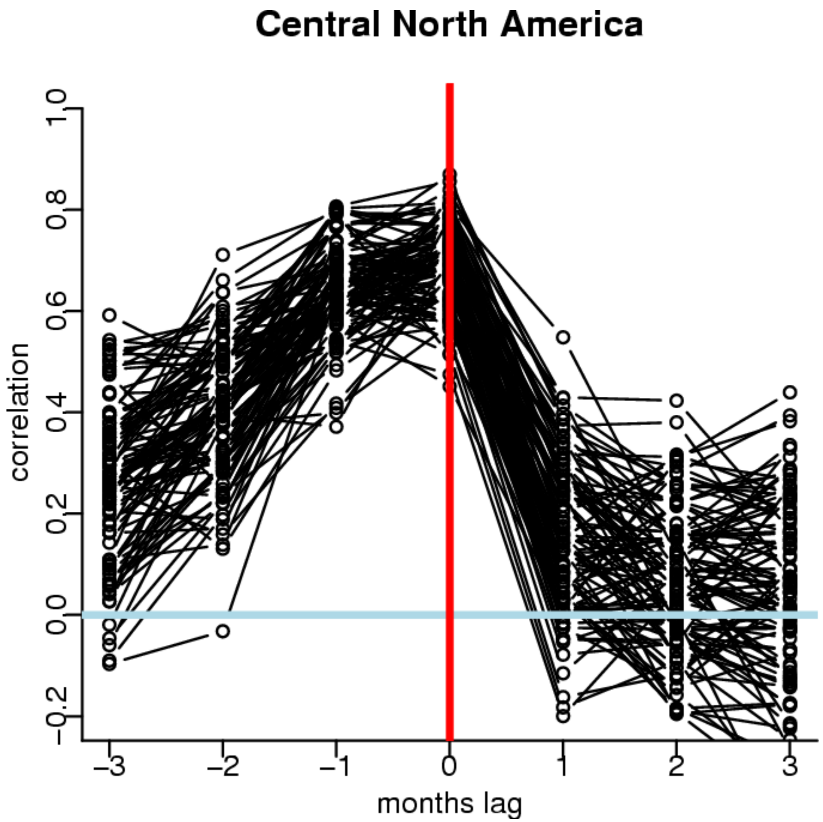
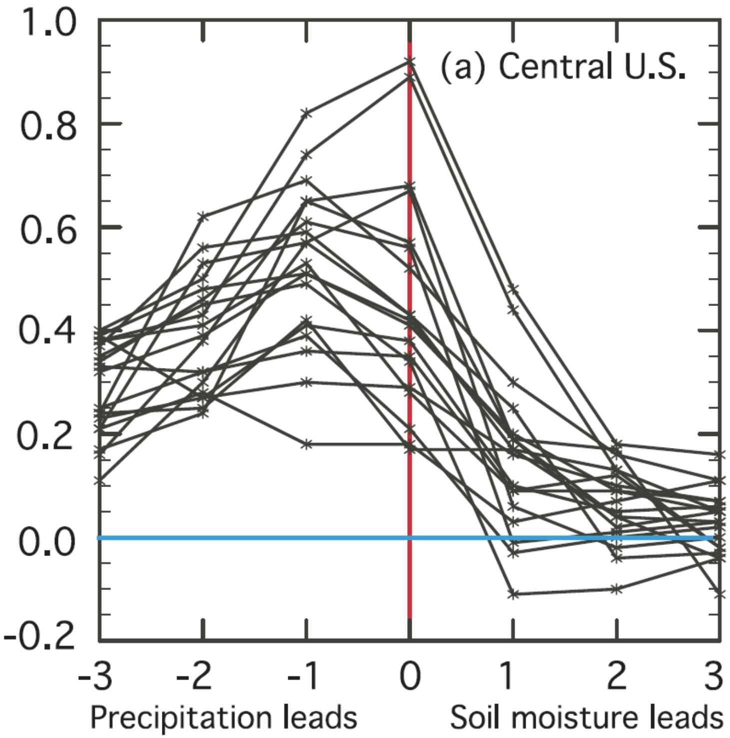
Coupling CLM pert. exp. vs. CMIP3



Notaro et al. 2008



- ***Range of correlations in CLM ensemble exceeds the range of CMIP3 models!***
- ***Note that simulation length is much shorter (-> larger spread)***

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Summary and outlook

- Uncertainties in land surface parameters contribute to relatively large range of realizations of current climate and of responses to doubling of CO_2, particularly at regional scale
- Land surface parameters have larger effect on extremes than on mean climate
- Simple analyses indicate that soil moisture memory and land-atmosphere coupling is highly sensitive to choice of land surface parameters

Next steps:

- Analysis of widely-used drought and heat wave indices
- Validation with observational data sets and comparing of ensemble range against CMIP3 runs
- Detailed analysis of soil moisture memory and coupling strength

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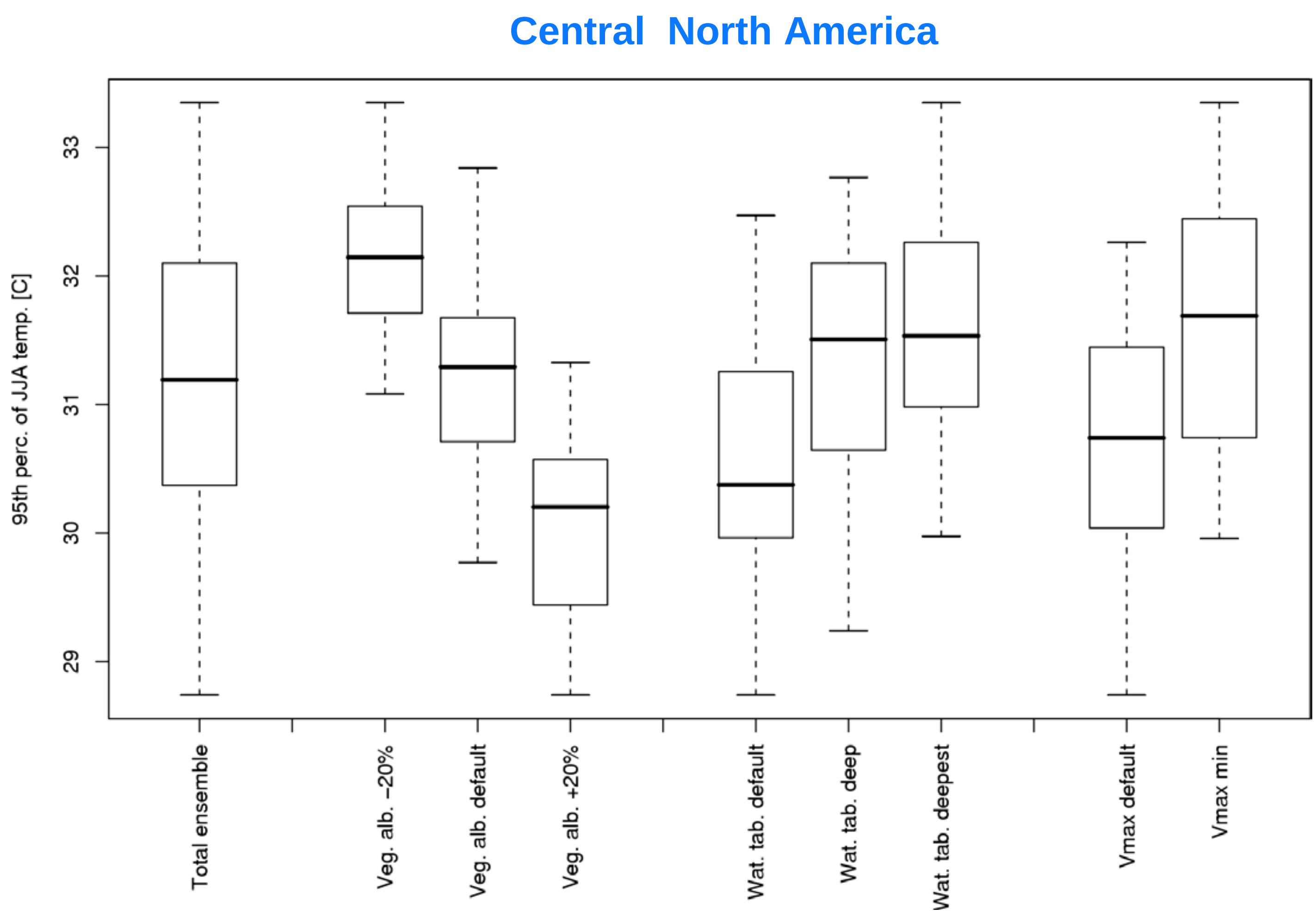
Parameter determining JJA 95th percentile



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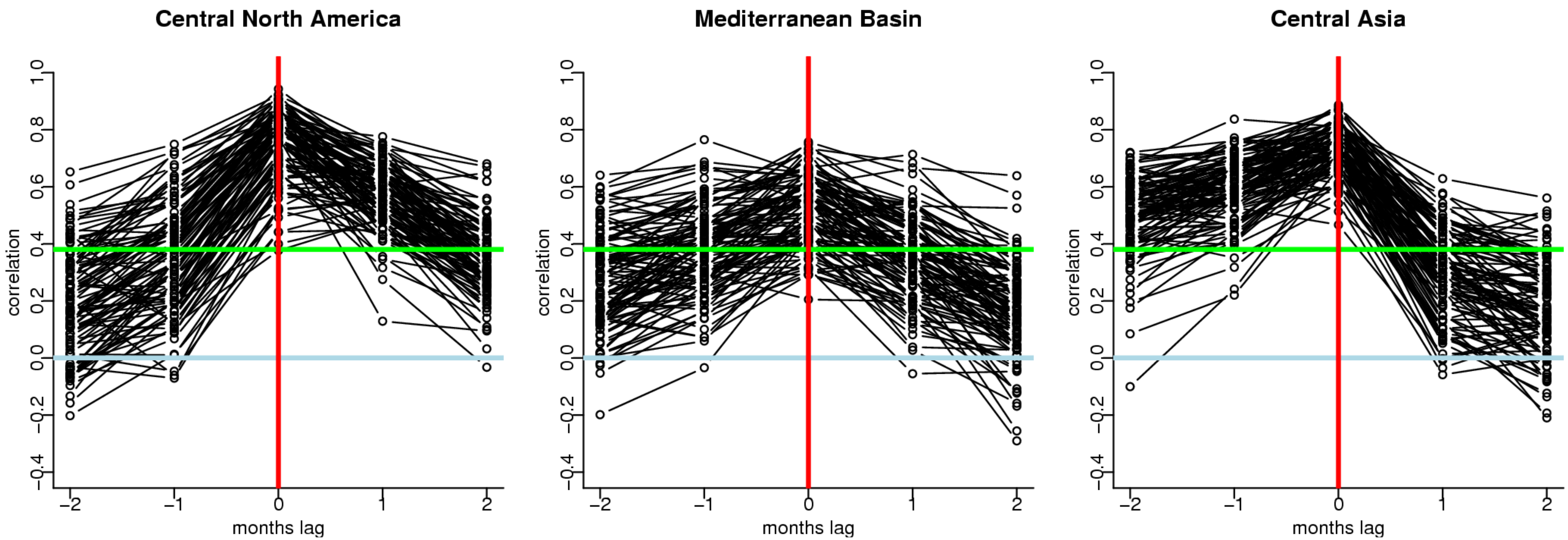
Soil moisture-evapotranspiration coupling



- ***Very simple approach to determine soil moisture-precipitation coupling***
- ***Generally low soil moisture-precipitation coupling***
- ***Range of correlation between members is very large***

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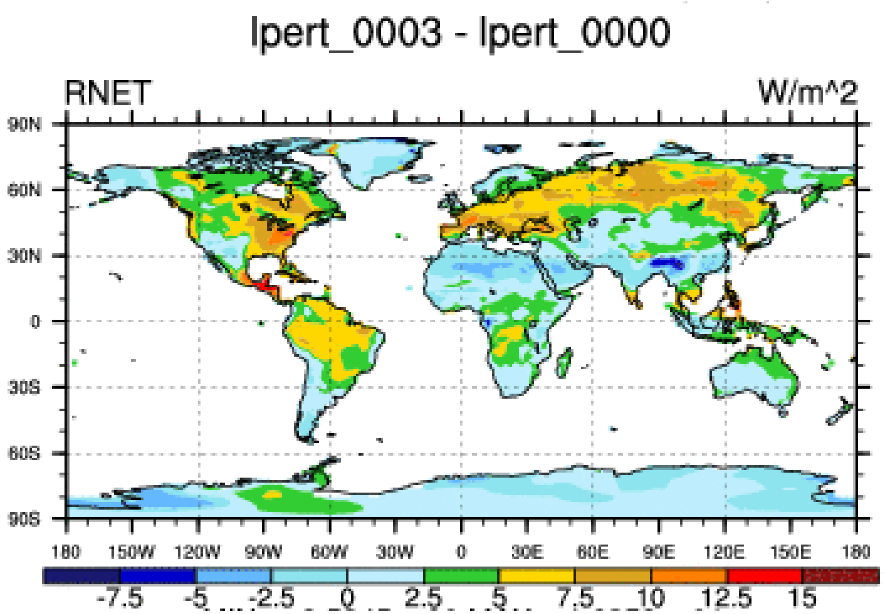
Vegetation albedo

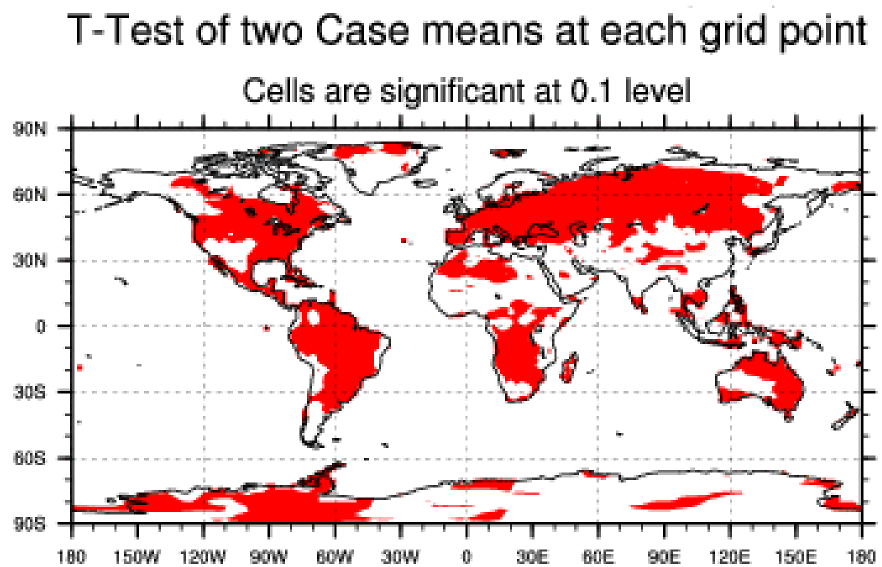
Table 2: α_{leaf} *leaf albedo*

	α_{vis}^{leaf} std	min	max	α_{nir}^{leaf} std	min	max
NET temperate	0.070	0.056	0.084	0.350	0.280	0.420
NET boreal	0.070	0.056	0.084	0.350	0.280	0.420
NDT boreal	0.070	0.056	0.084	0.350	0.280	0.420
BET tropical	0.100	0.080	0.120	0.450	0.360	0.540
BET temperate	0.100	0.080	0.120	0.450	0.360	0.540
BDT tropical	0.100	0.080	0.120	0.450	0.360	0.540
BDT temperate	0.100	0.080	0.120	0.450	0.360	0.540
BDT boreal	0.100	0.080	0.120	0.450	0.360	0.540
BES temperate	0.070	0.056	0.084	0.350	0.280	0.420
BDS temperate	0.100	0.080	0.120	0.450	0.360	0.540
BDS boreal	0.100	0.080	0.120	0.450	0.360	0.540
C_3 grass arctic	0.110	0.088	0.132	0.580	0.464	0.696
C_3 grass	0.110	0.088	0.132	0.580	0.464	0.696
C_4 grass	0.110	0.088	0.132	0.580	0.464	0.696
Crop1	0.110	0.088	0.132	0.580	0.464	0.696
Crop2	0.110	0.088	0.132	0.580	0.464	0.696

Vegetation albedo perturbed by +/- 20%, which represents approx. the maximum regional bias

Low veg. albedo vs. CTL (JJA)





Annual global land energy budget:

net radiat.:	**+2.0 W/m^2**
latent heat:	**+0.7 W/m^2**
sensible heat:	**+1.3 W/m^2**

Changes in net radiation mainly over crop and grass (largest perturbation)

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Snow albedo – snow aging

$$\alpha_{sno,\wedge} = [1 - C_{\wedge} F_{age}] \alpha_{sno,\wedge,0}$$

	Standard	Minimum	Maxiumum
fresh snow albedo (VIS)	0.95		
fresh snow albedo (NIR)	0.65		
$C_{\wedge}$ (VIS)	0.2	0.02	0.38
$C_{\wedge}$ (NIR)	0.5	0.05	0.85

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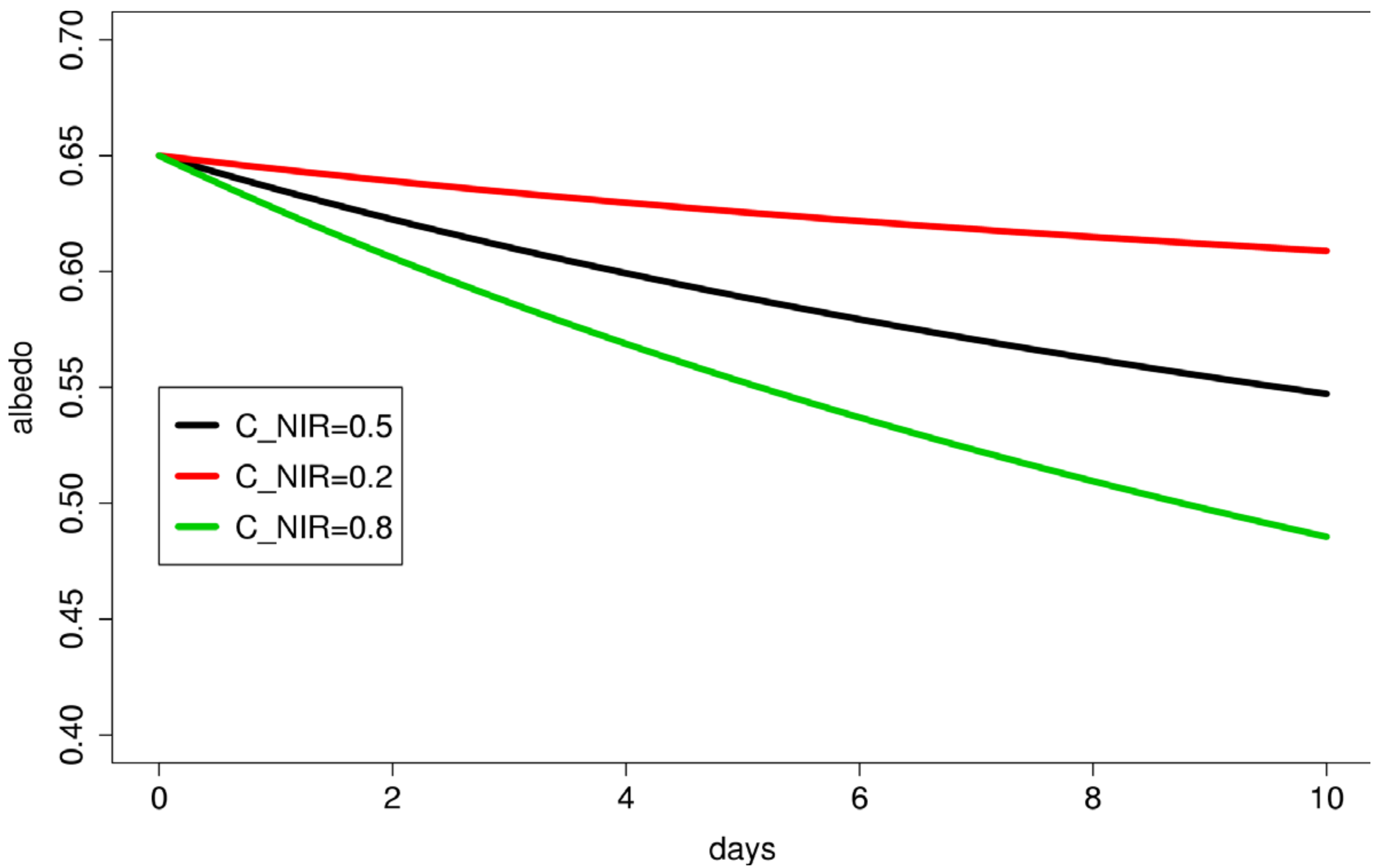
Snow albedo (near-infrared) – snow aging



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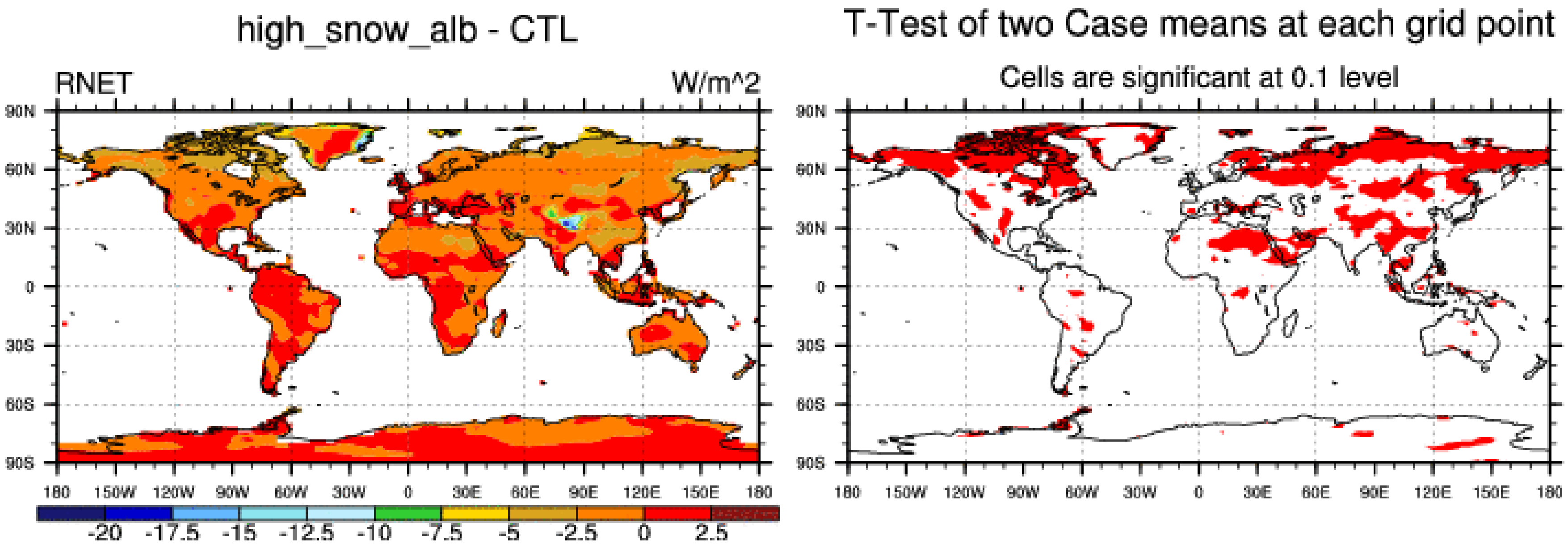
Snow albedo – snow aging



Global land net radiation -0.64 W/m^2

Effects strongest in spring and over Tibetan Plateau

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Perturbed land parameter experiment

Roughness length z_0(m):					
Dense evergreen needleleaf forest		0.50[40]	0.78[41]	2.00[42]	
Dense deciduous needleaf forest		0.50[40]	0.78[41]	2.00[42]	
Dense deciduous broadleaf forest		0.50[40]	0.70[41]	2.00[42]	
Equatorial rainforest			1.05[40]	2.10[41]	2.90[42]
No. soil lev. Access. For t/piration (forest/grass)	2/1[43]	3/2[44]	4/3		
Surface-cancopy decoupling scheme			Off	On [45]	
Stomatal conductance response to ΔCO_2		Off[46]	On		

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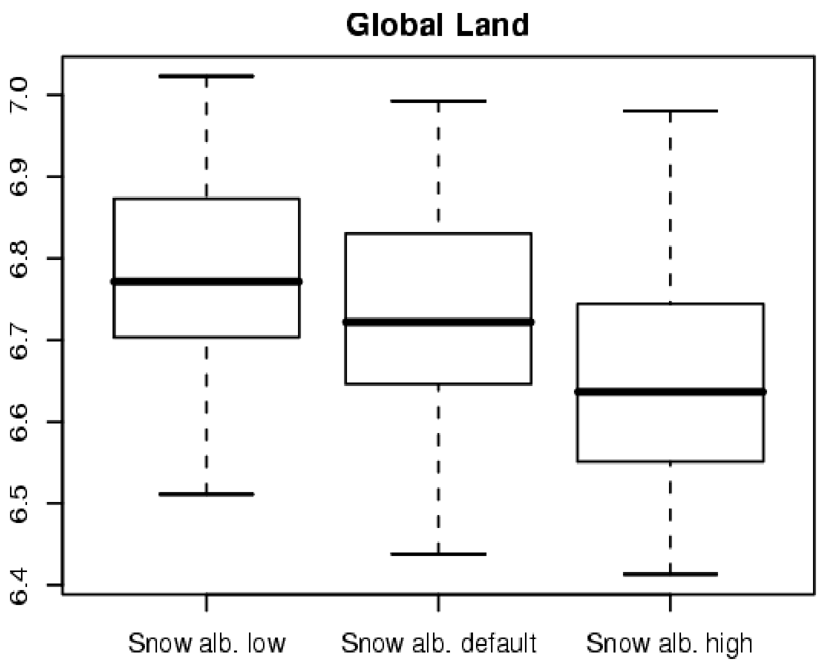
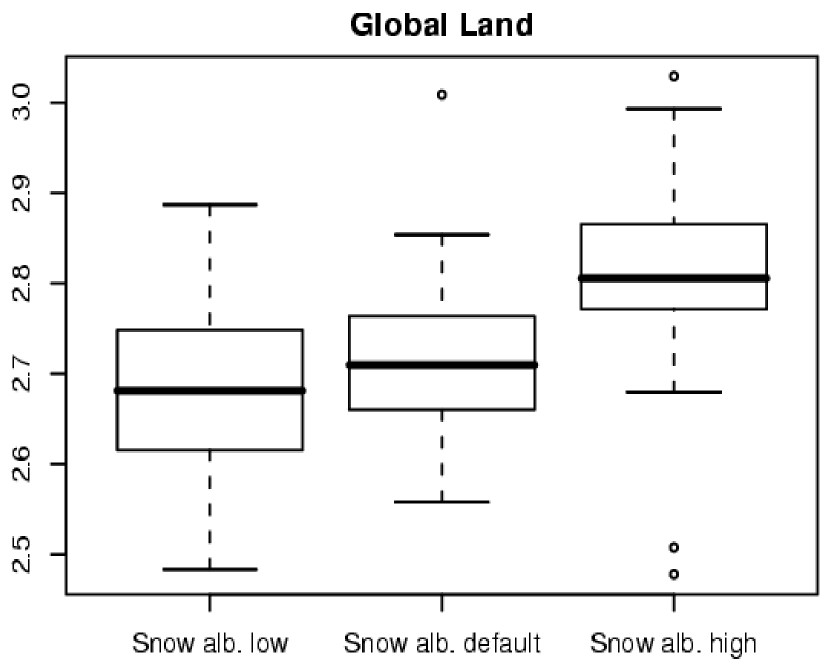
DJF temperatures vs. snow albedo

Snow albedo vs. CTL DJF temp.



Snow albedo vs. Δtemp.



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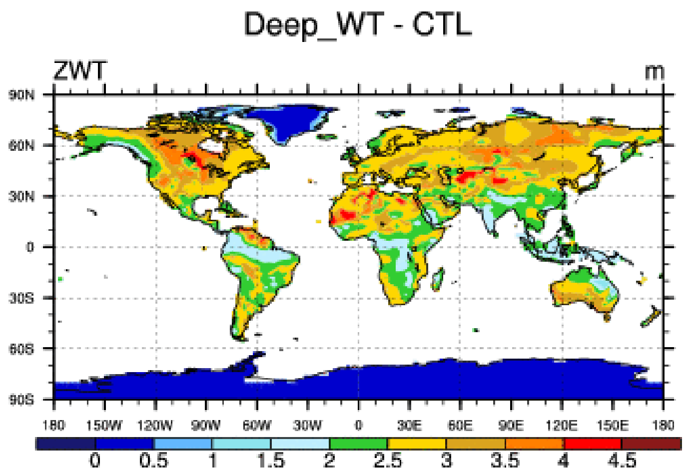
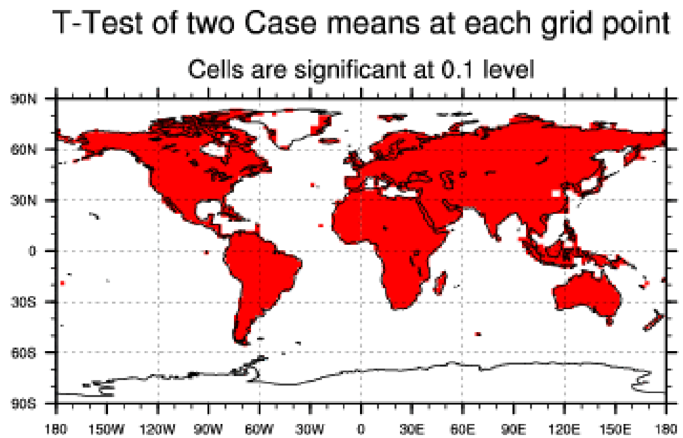
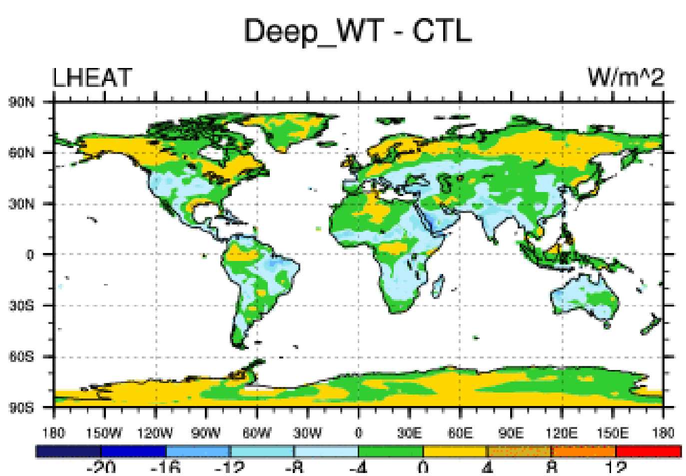
Decay factor affecting water table depth

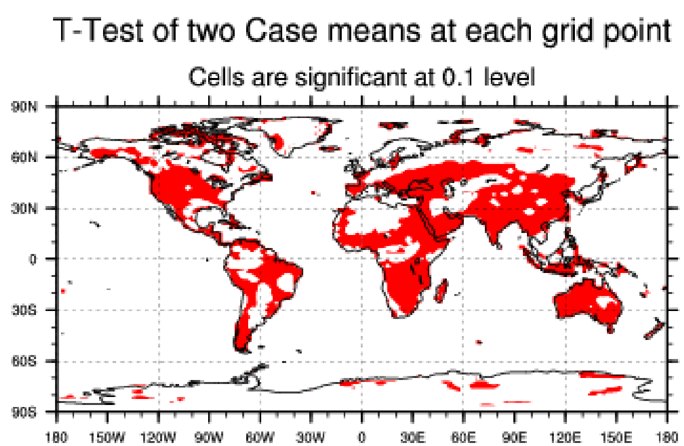
Water table depth





Latent heat flux





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Roughness length

PFT	ztop [m]	z0m CLM3.5	z0m ECMWF
NET temperate	17	0.935	2
NET boreal	17	0.935	2
NDT boreal	14	0.77	2
BET tropical	35	2.625	4
BET temperate	35	2.625	4
BDT tropical	18	0.99	2
BDT temperate	20	1.1	2
BDT boreal	20	1.1	2
BES	0.5	0.06	0.1
BDS temperate	0.5	0.06	0.1
BDS boreal	0.5	0.06	0.1
C3 Grass	0.5	0.06	0.02-0.05
C3 non-arctic grass	0.5	0.06	0.02-0.05
C4 Grass	0.5	0.06	0.1
Corn	0.5	0.06	0.15
Wheat	0.5	0.06	0.15

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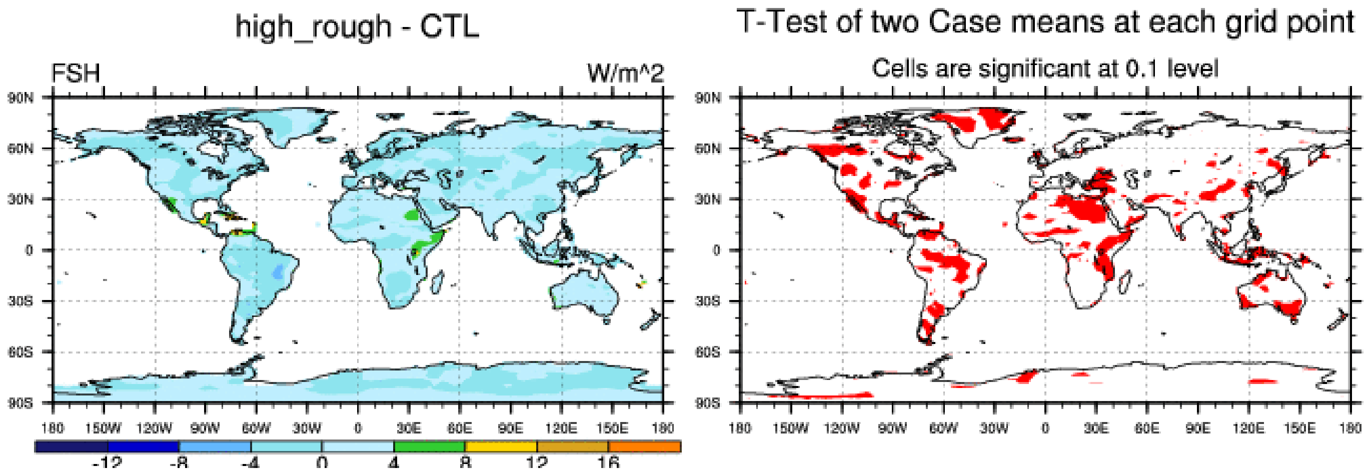
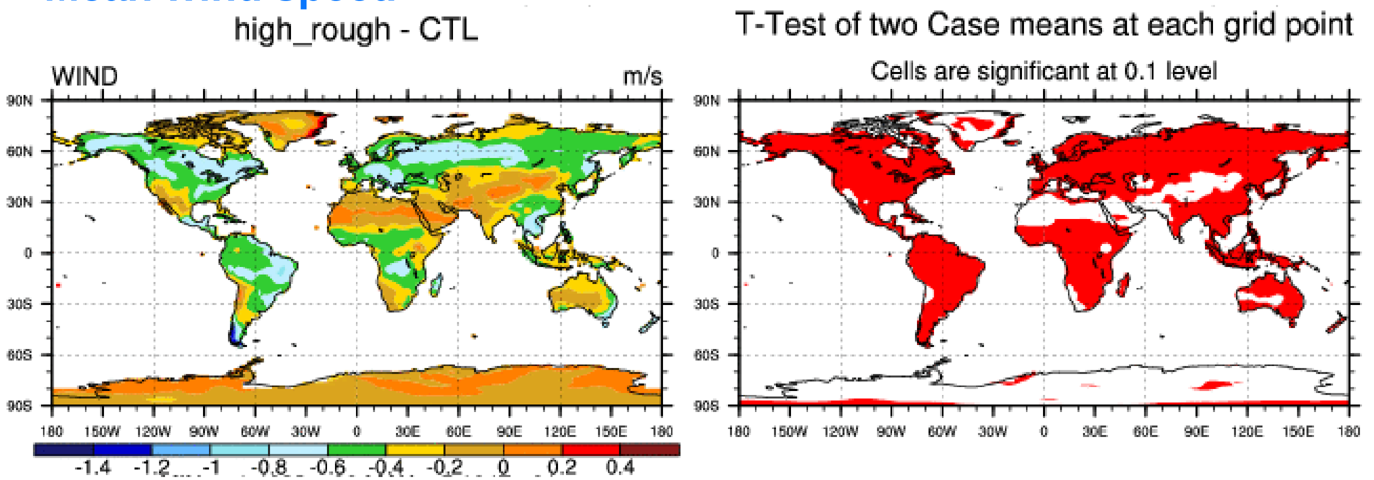
Roughness length

Sensible heat flux



Mean wind speed



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Model experiment

108 (3*3*3*2*2) simulations of 75 (15+30+30) years
-> 8100 model years (approx. 10TB of data)

Tech. specs Jaguar (Cray XT5)
- 1.6 Petaflops
- 26,604 computing nodes (19'720 processors used in this experiment)
- 362 TB memory
- 10750 TB diskspace

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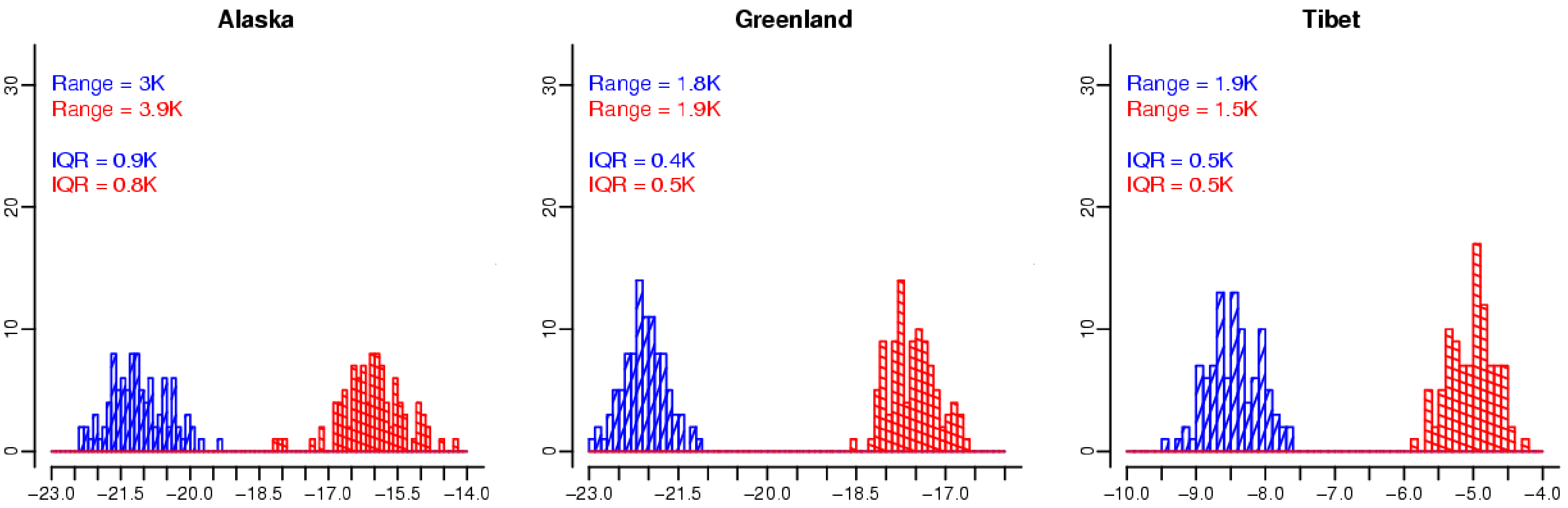
Regional DJF temperatures

DJF mean temperatures



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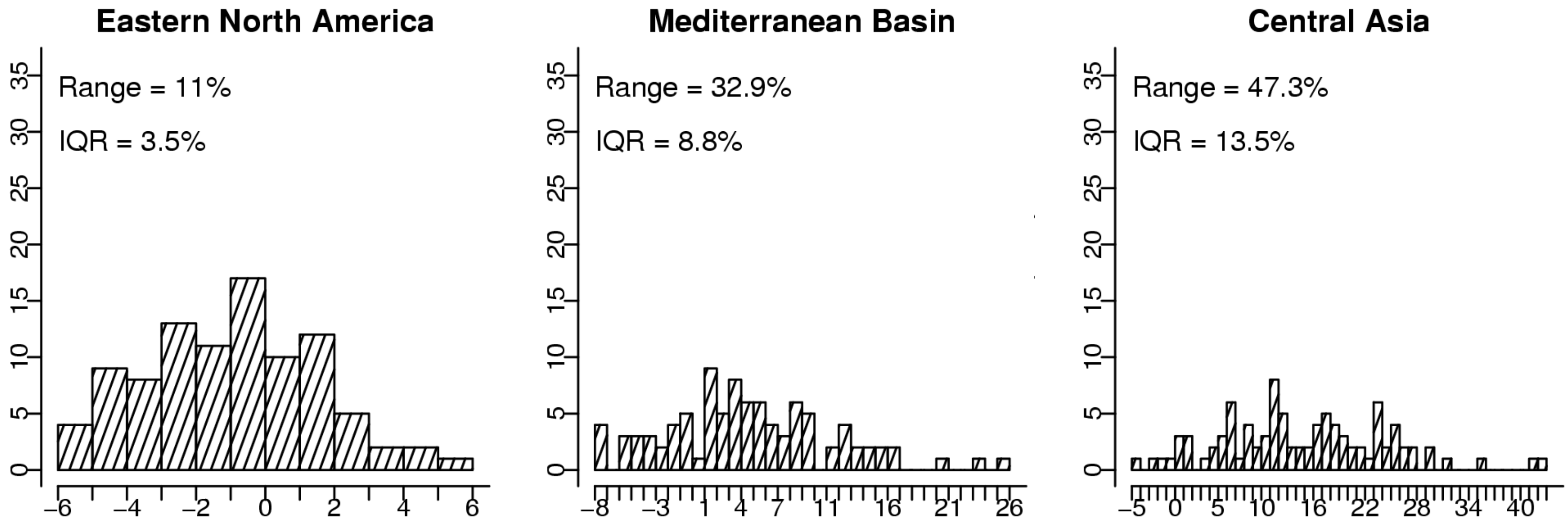
Regional intense precipitation (95th perc.)



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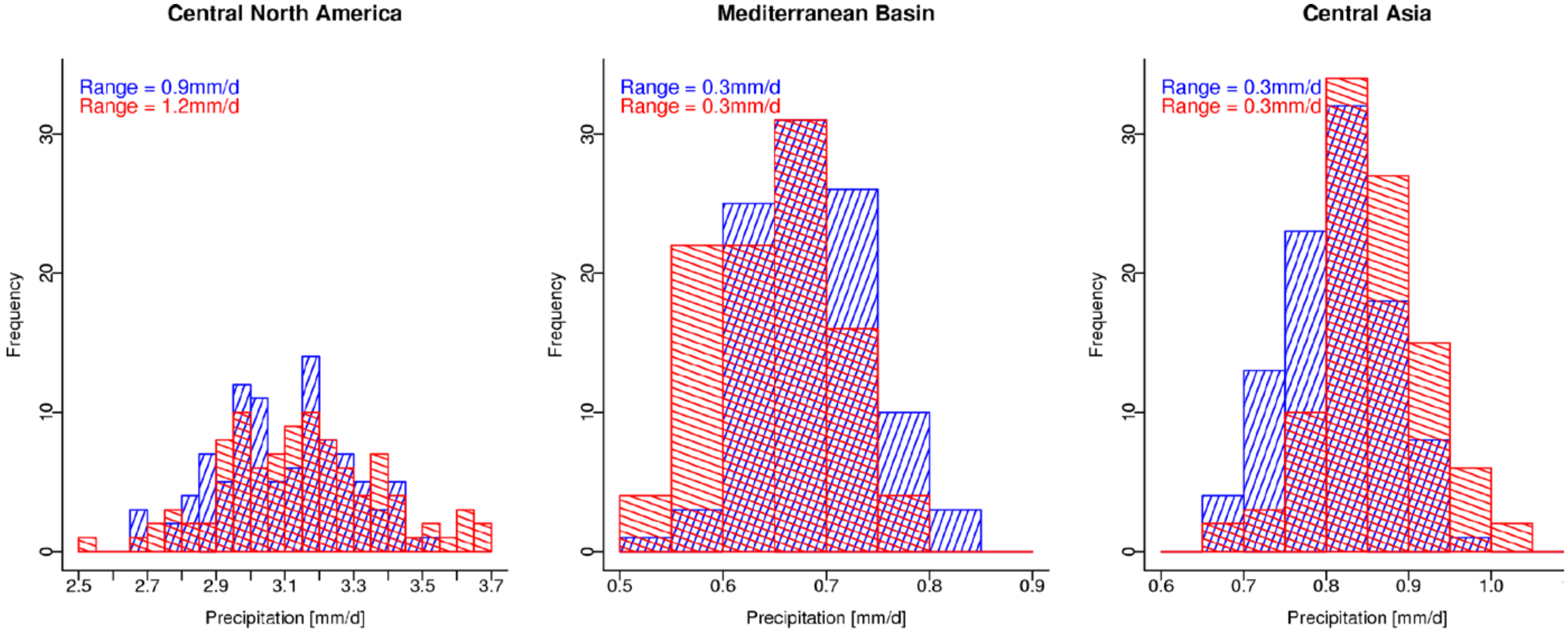
Regional JJA precipitation



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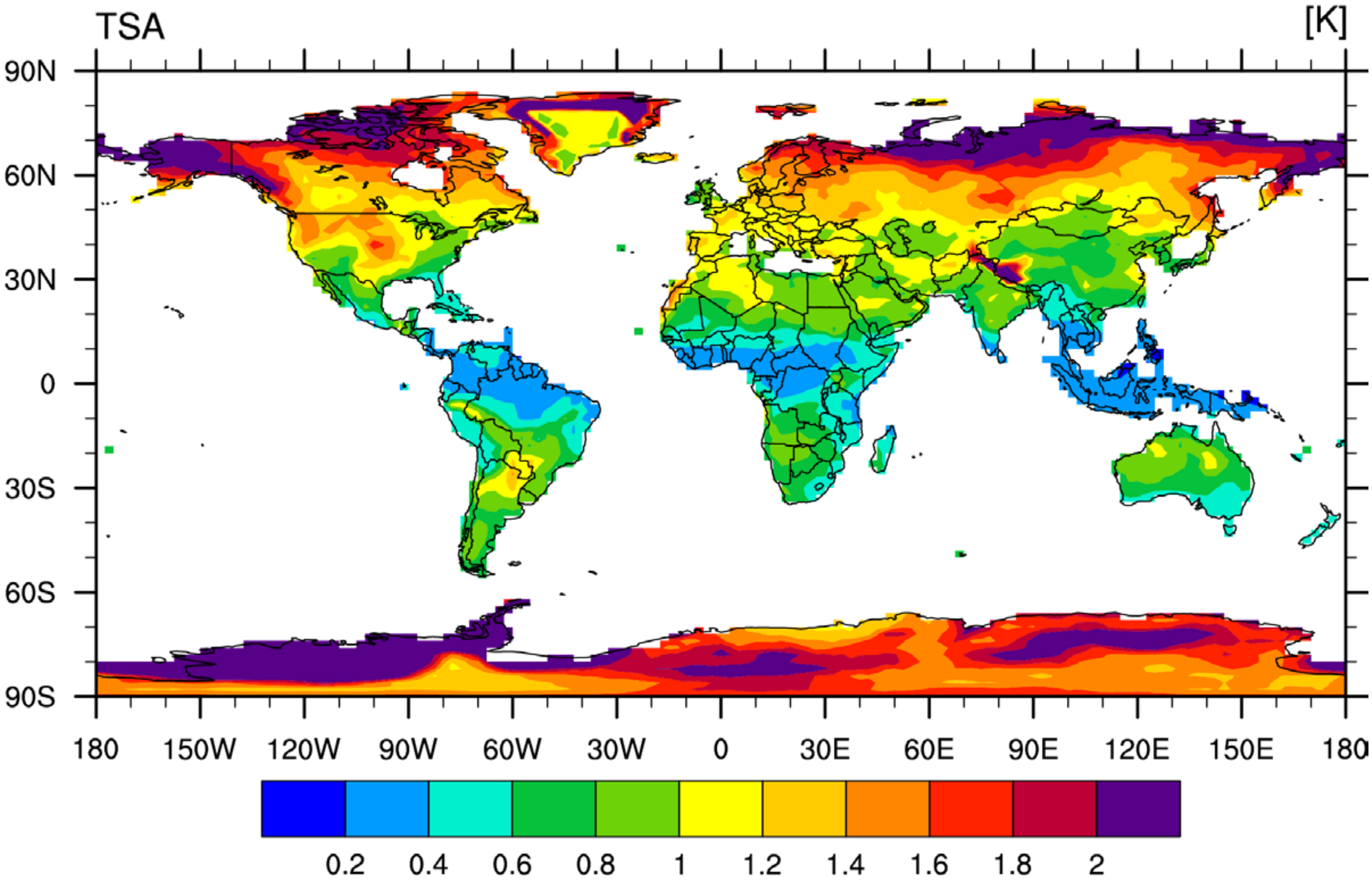
Range of JJA temp. response to 2xCO2



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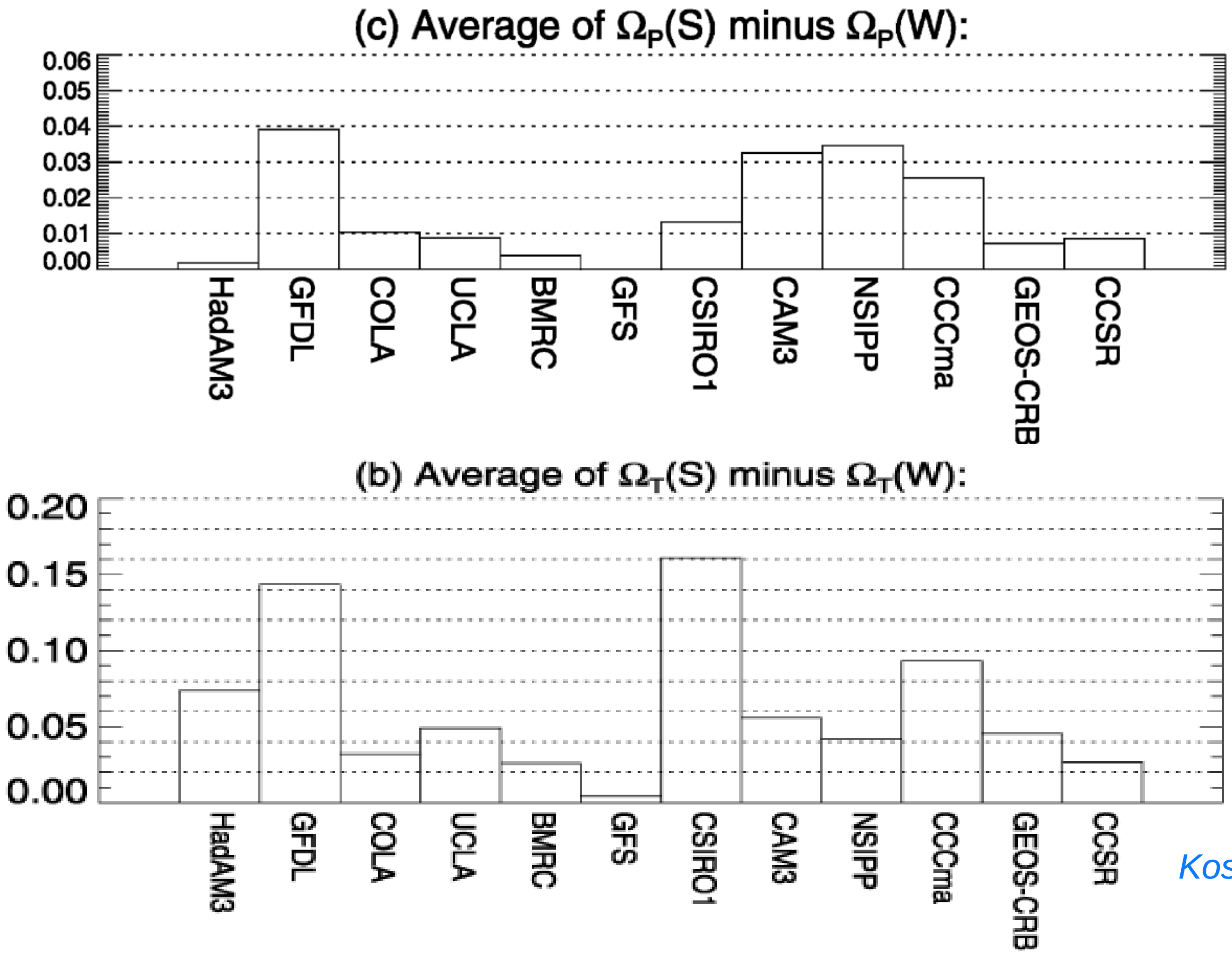
Land-atmosphere coupling (GLACE)



Land surface-precipitation/temperature coupling strength differs substantially between models

Koster et al. 2006