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CLMCUBE - 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

- Land surface processes/feedbacks act on subgrid scale and need to be parameterized
- Important source of uncertainty in climate projections

Objective

- Quantifying uncertainties in temperature and precipitation extremes induced by land surface parameterizations

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Experimental setup

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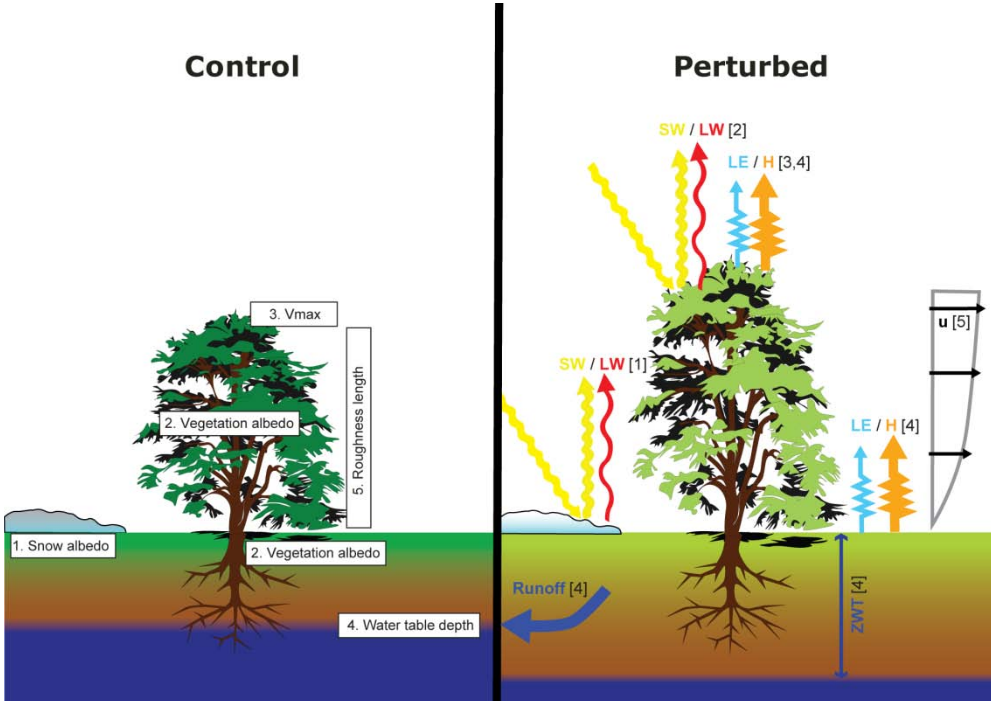
Experimental setup

- CCSM 3.5 with mixed-layer ocean

- Perturbation of 5 poorly constrained CLM parameters
- Different combinations of perturbed parameters
  -> 108 ensemble members

- Simulations with $1xCO_2$ (30 years) and $2xCO_2$ (20 years)



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Response to 2xCO_2

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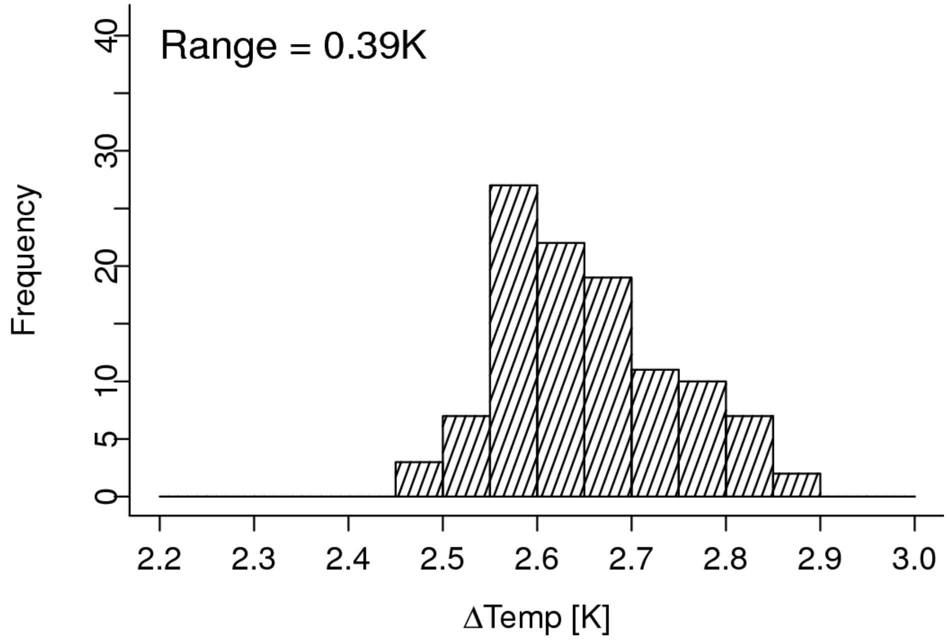
Global land temperature response



$\Delta Temp_{Land} = 2.65K$

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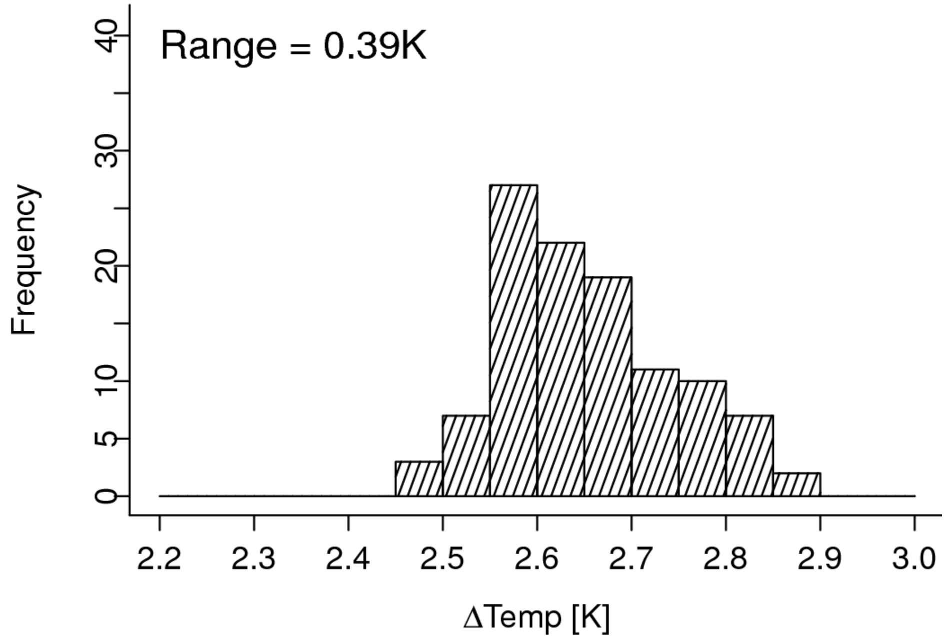
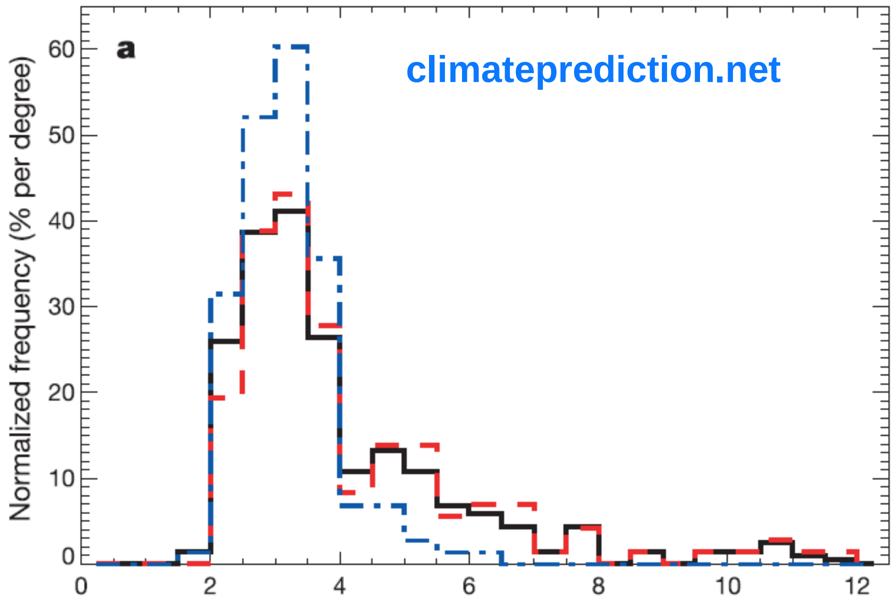
Global land temperature response





Stainforth et al. 2005

Range smaller than in PPEs focusing on atmospheric parameter uncertainties

Uncertainties in CAMCUBE are only 2.5 times larger than CLMCUBE

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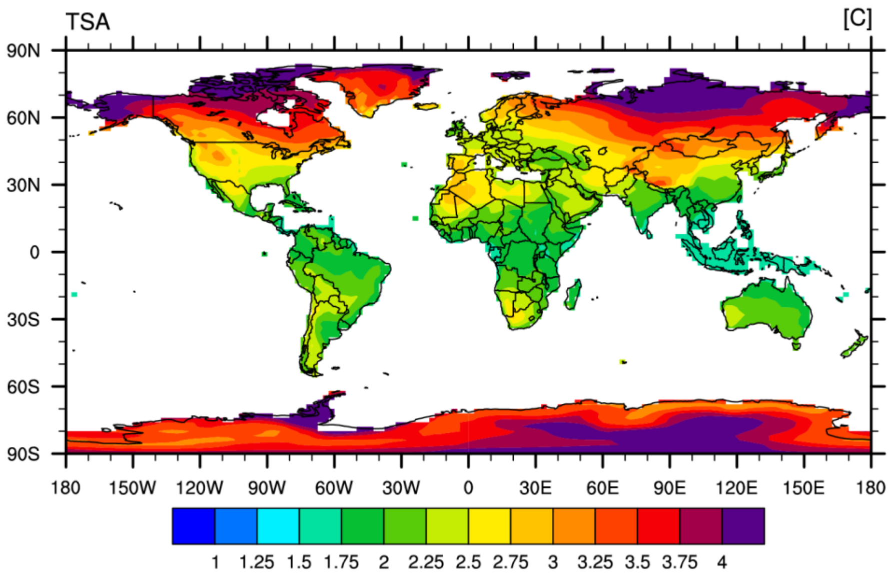
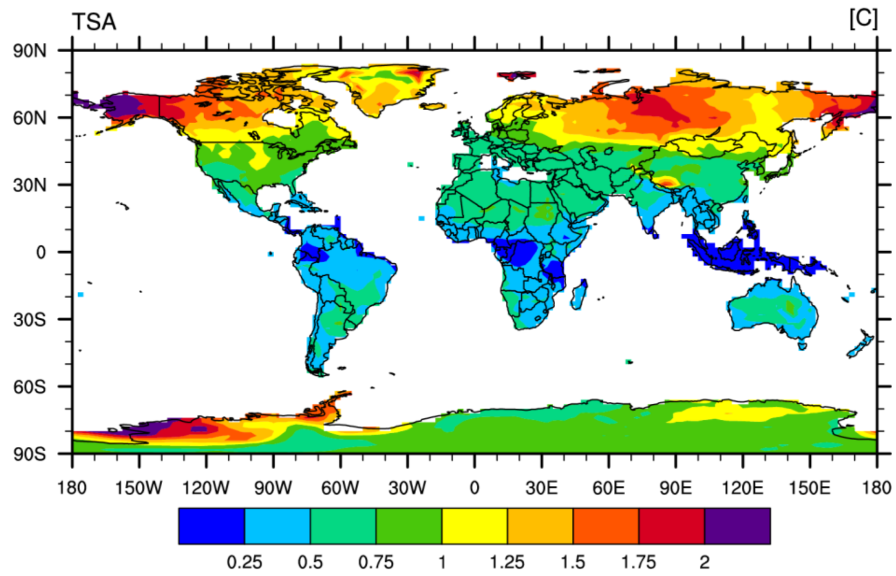
Temperature response to $2xCO_2$

Ensemble mean response



Uncertainty (ensemble range)



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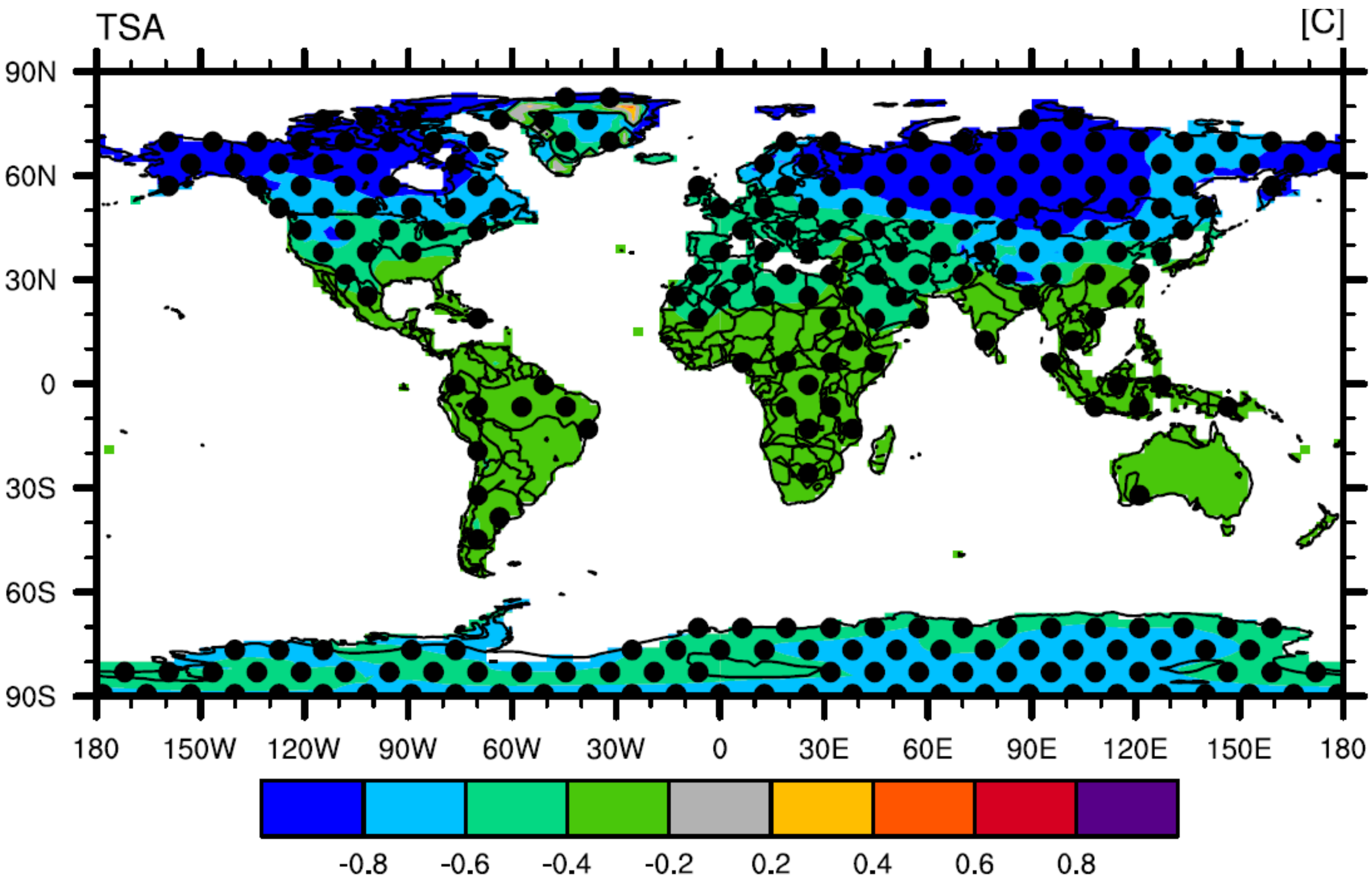
Low snow albedo vs. high snow albedo



Models with low present-day snow albedo show weaker warming

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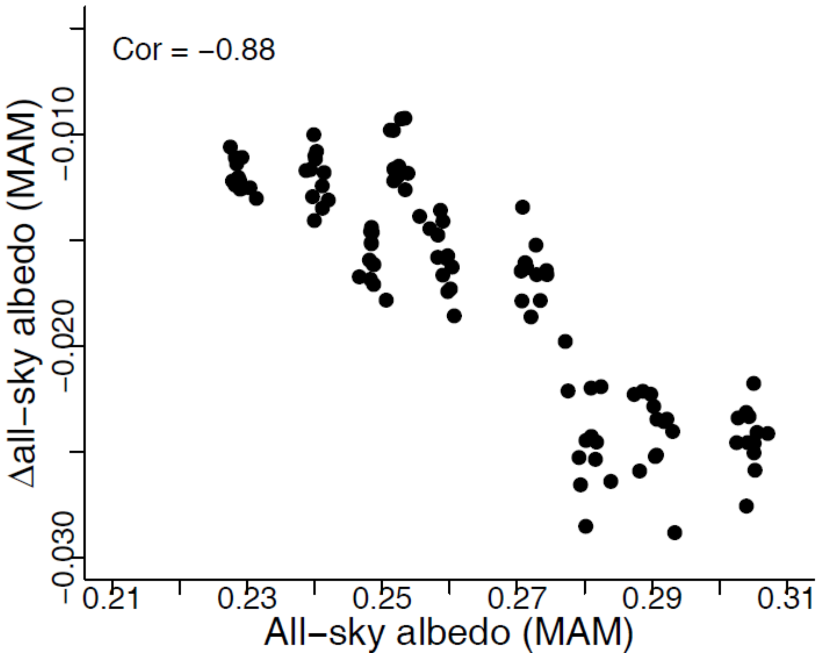
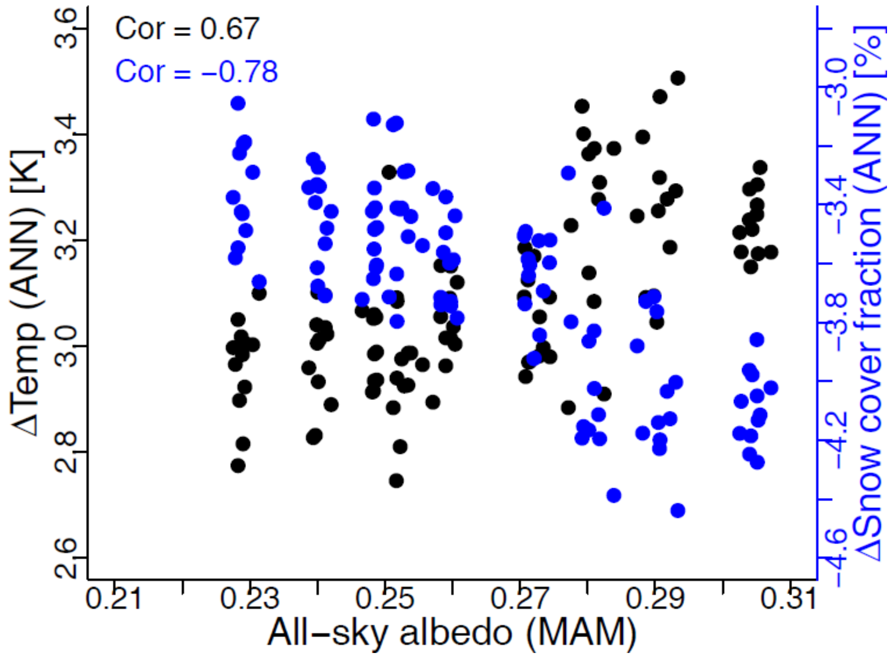
Snow albedo feedback





Present-day snow albedo can be used to constrain ΔTemp (cf. Qu and Hall 2006, Levis et al. 2008)

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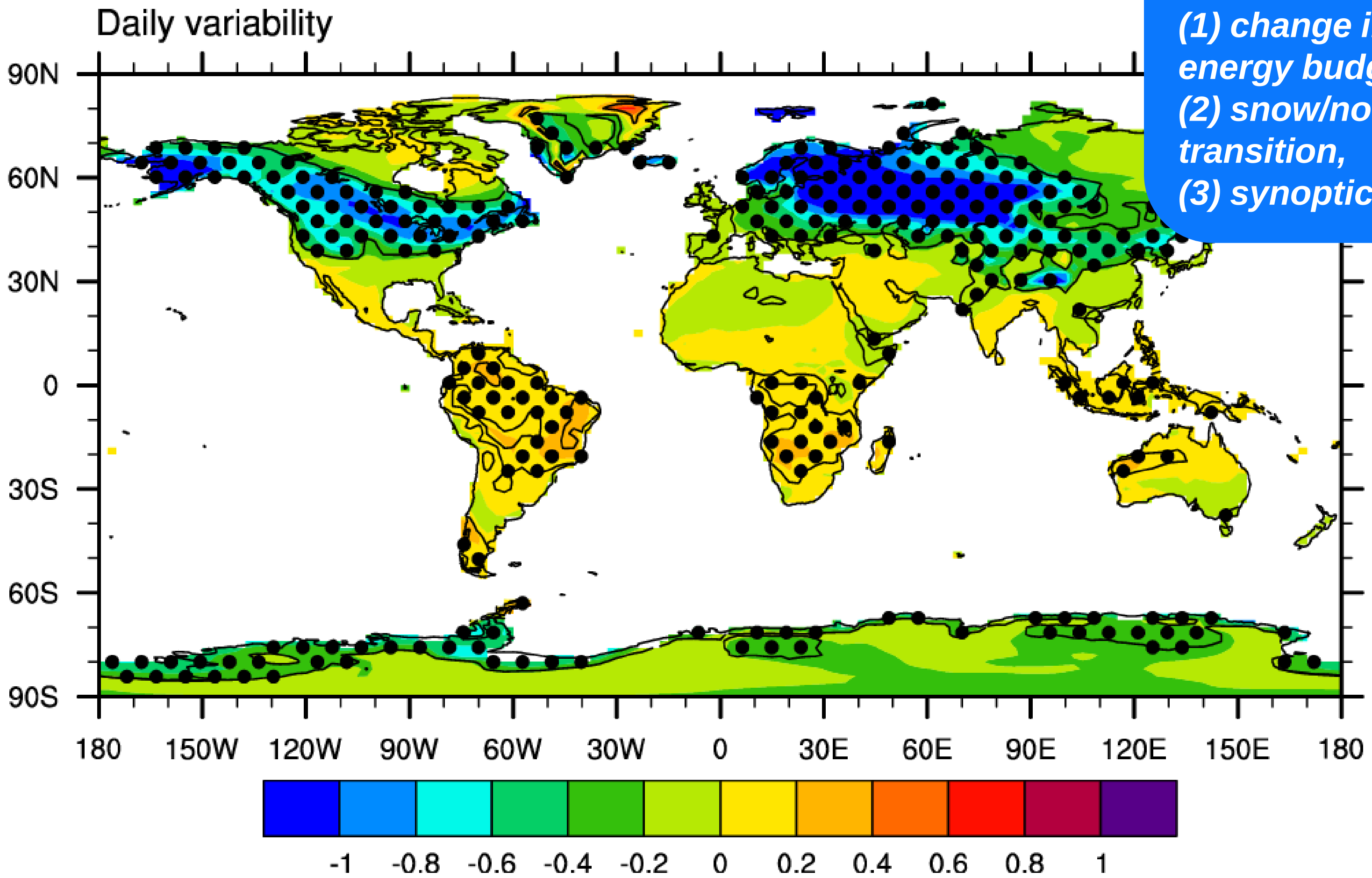
DJF variability response to $2xCO_2$

Variability reduction over strongest snow melting!

Mechanisms:
(1) change in surface energy budget,
(2) snow/no snow transition,
(3) synoptic variability



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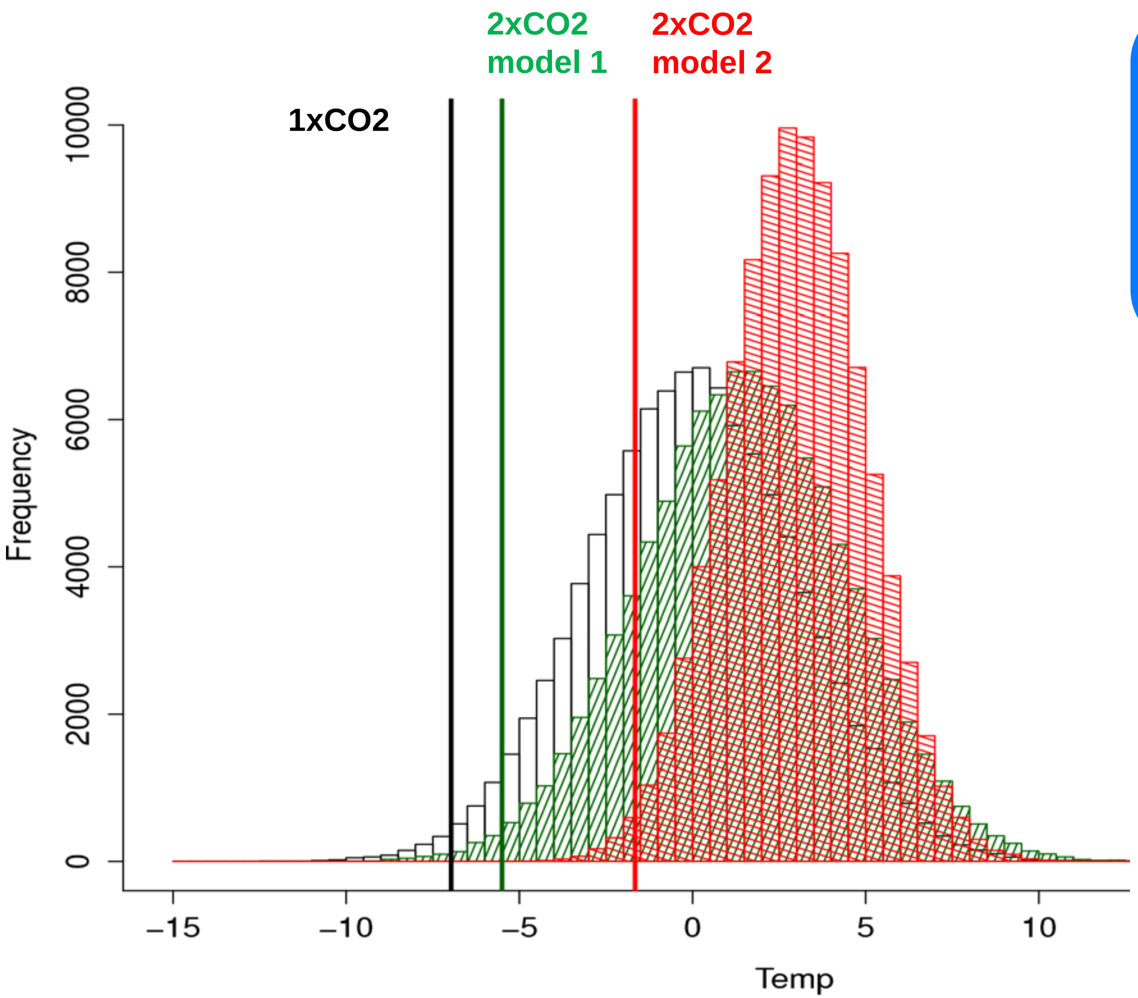
Role of reduced DJF variability



Reduction in variability amplifies change in cold extremes

Models with strong DJF warming show strong variability reduction

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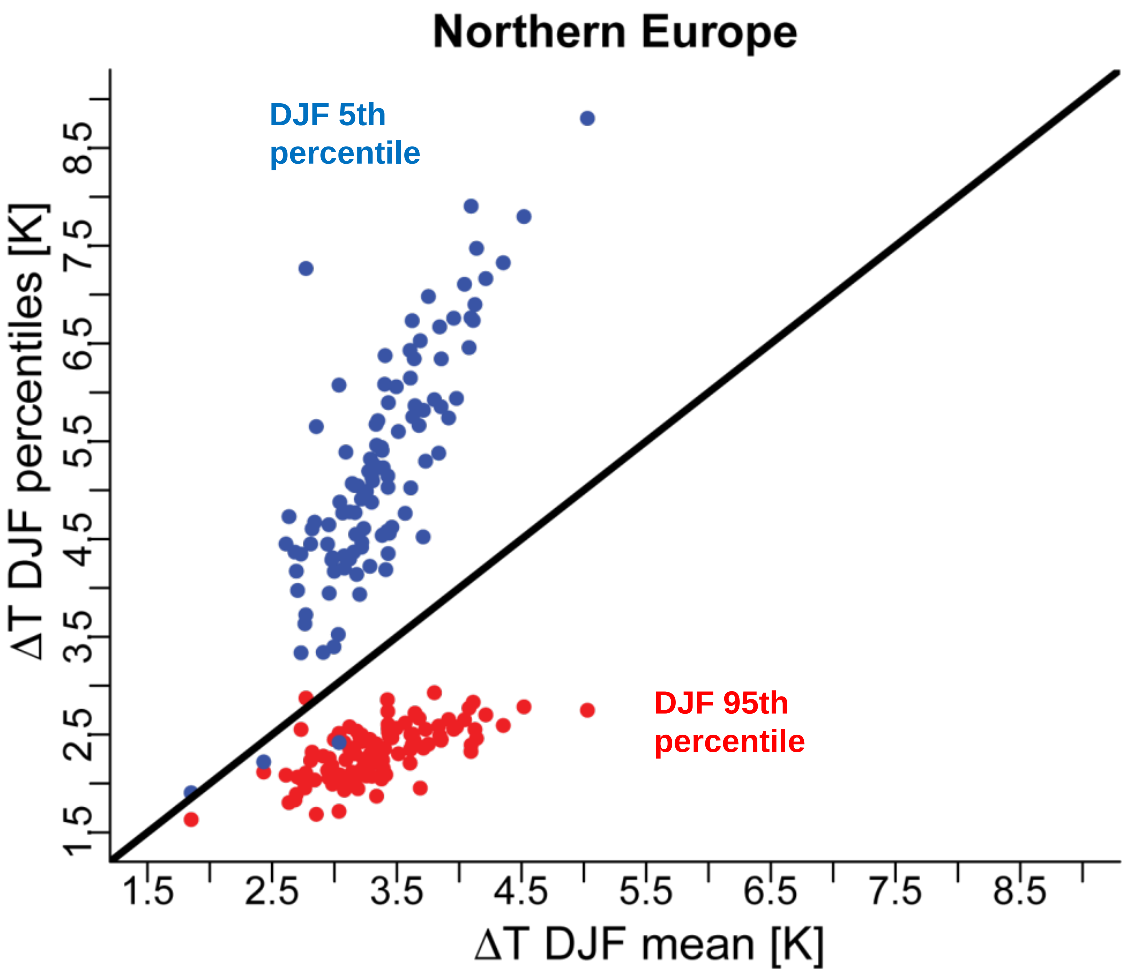
Cold extremes are amplified



- *More DJF warming -> amplified warming of cold extremes*

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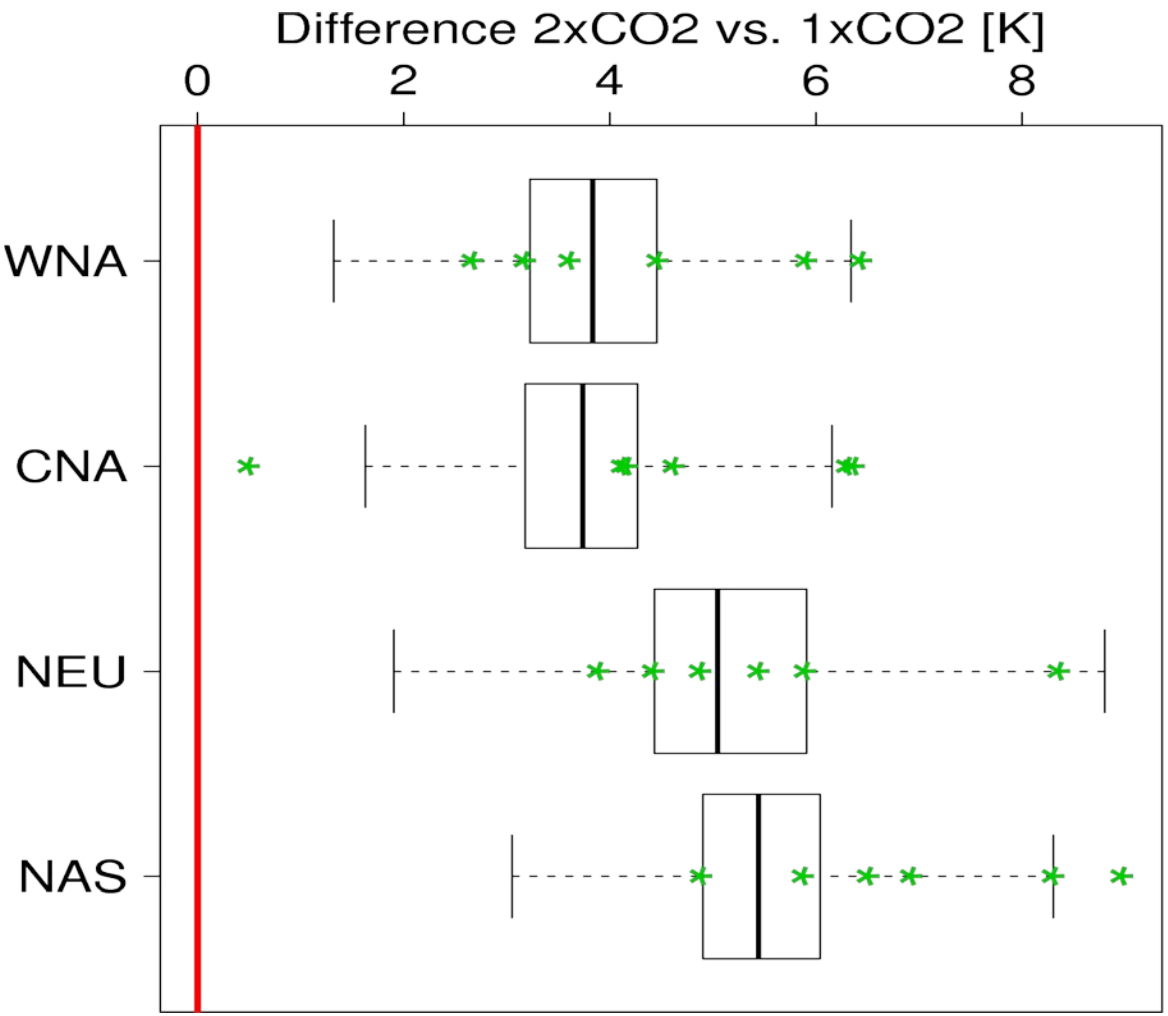
Uncertainties in cold extremes (DJF 5th perc.)



Uncertainties regionally exceed the uncertainties of 6 CMIP 3 models providing daily output

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Conclusions

- Land surface parameterizations induce major uncertainties in response of temperature extremes
- Variability response to $2xCO_2$ is particularly sensitive to land surface parameters
- Variability and mean response often relate to similar processes -> uncertainties add up

- Hot extremes show somewhat smaller uncertainties
- Response for precipitation-related indices, e.g. consecutive dry summer days differs in sign over Mediterranean, Australia, Central North America

References:

- **Fischer, E.M., D. Lawrence, B. Sanderson, 2010, *submitted to Clim. Dynam.***

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Summer precipitation and droughts

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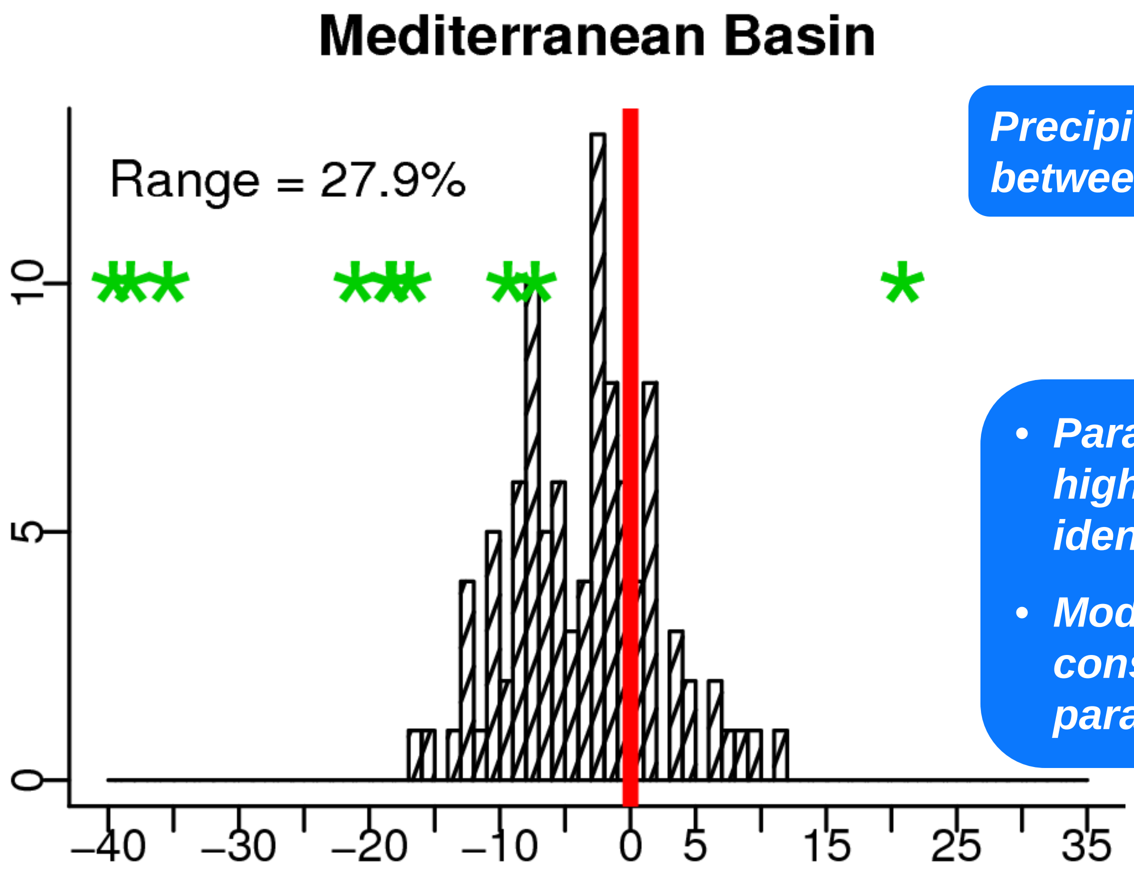
Precipitation response to 2xCO_2 (JJA)



Precipitation response varies between -17% and +12%

- *Parameters explaining highest variance are identified*
- *Model developers will constrain sensitive parameters*

Fischer et al. 2009c, *in prep*

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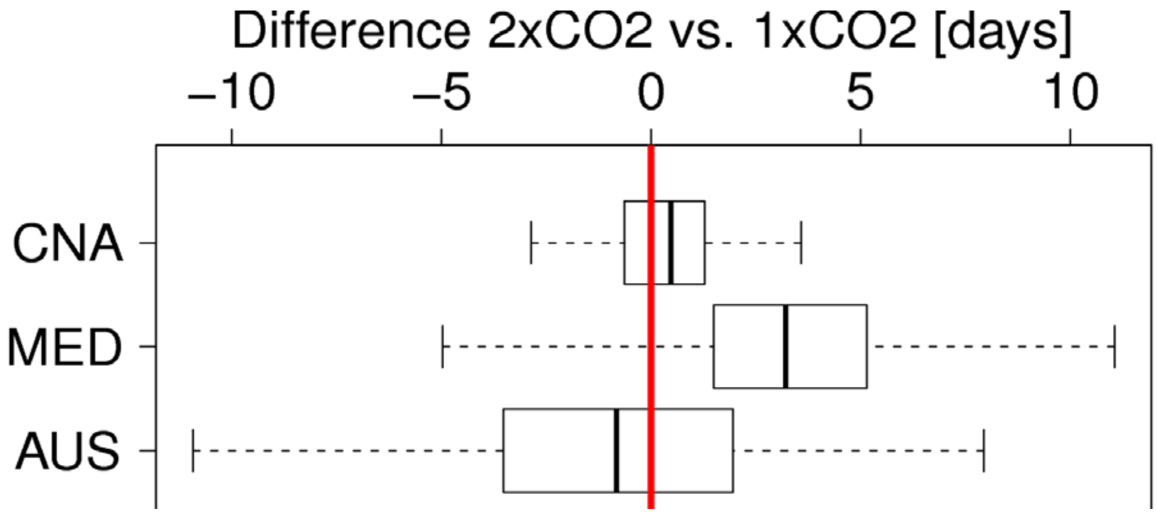
Consecutive dry days (<1mm/d)



- ***Large uncertainties in meteorological drought conditions***

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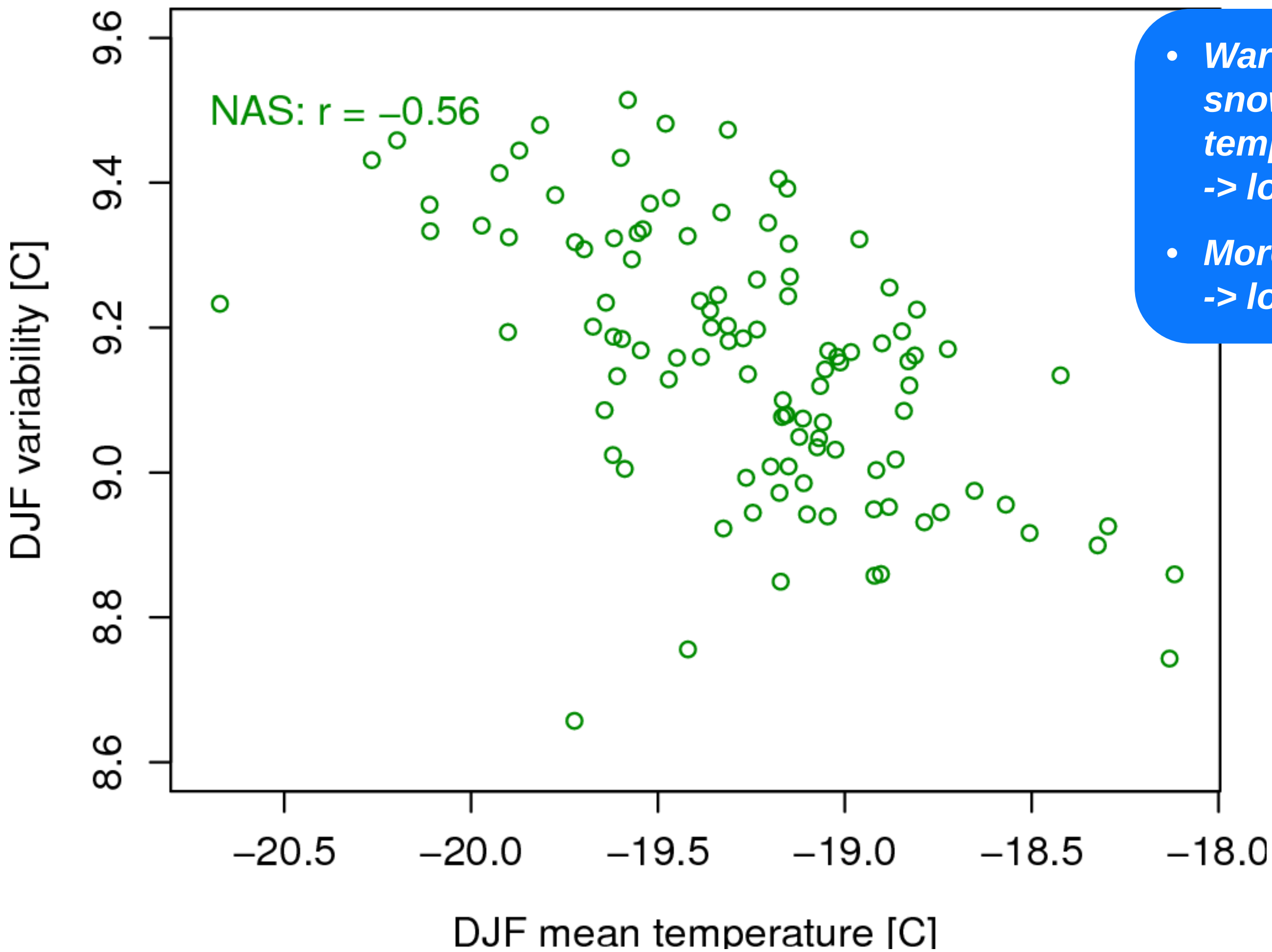
What mechanisms are driving DJF variability?



- *Warm models with low snow cover and warm temperatures -> low DJF variability*
- *More DJF warming -> lower variability*

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Present-day climate

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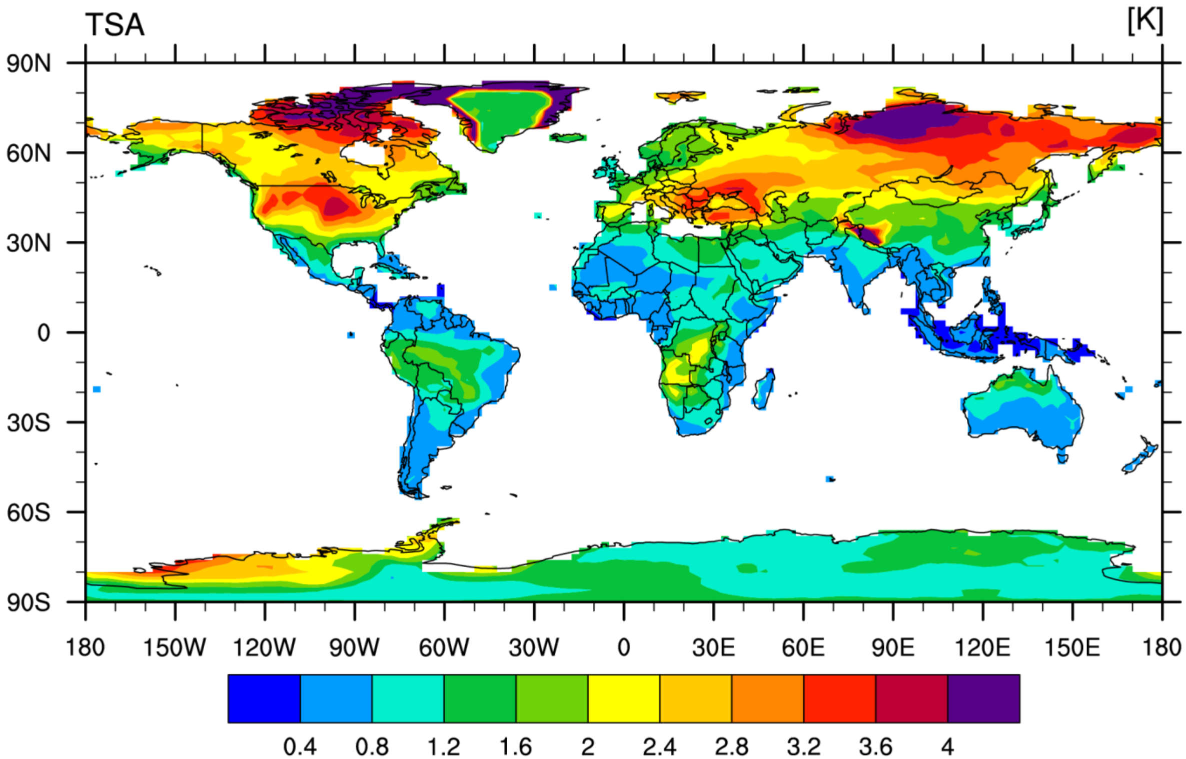
Role of parameters



- ***Parameters add nearly linearly in present-day (not for response to 2xCO_2)***
- ***Vmax and Wat. Table important over dry mid-latitudes***

Region	Expl. Var.	Veg. alb.	Snow alb.	Wat. table	Vc_{max}	Rough. l.
CN America	96%	62%	2%	13%	19%	1%
Australia (DJF)	65%	15%	0%	40%	11%	0%
N. Asia	96%	34%	38%	9%	16%	0%

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Experimental setup

Parameter perturbations

- Selected land surface parameters are poorly constrained by observations
- Perturbations should be justifiable and if possible based on literature and/or observational studies
- Parameters include 2 optical properties, 2 properties affecting water cycle and 1 turbulent property

Caveats

- Experiment covers by far not full range of uncertainty!
- Ocean circulation feedbacks are not accounted for
- Initial condition uncertainties are not systematically addressed
- Extremes are 'not very extreme'

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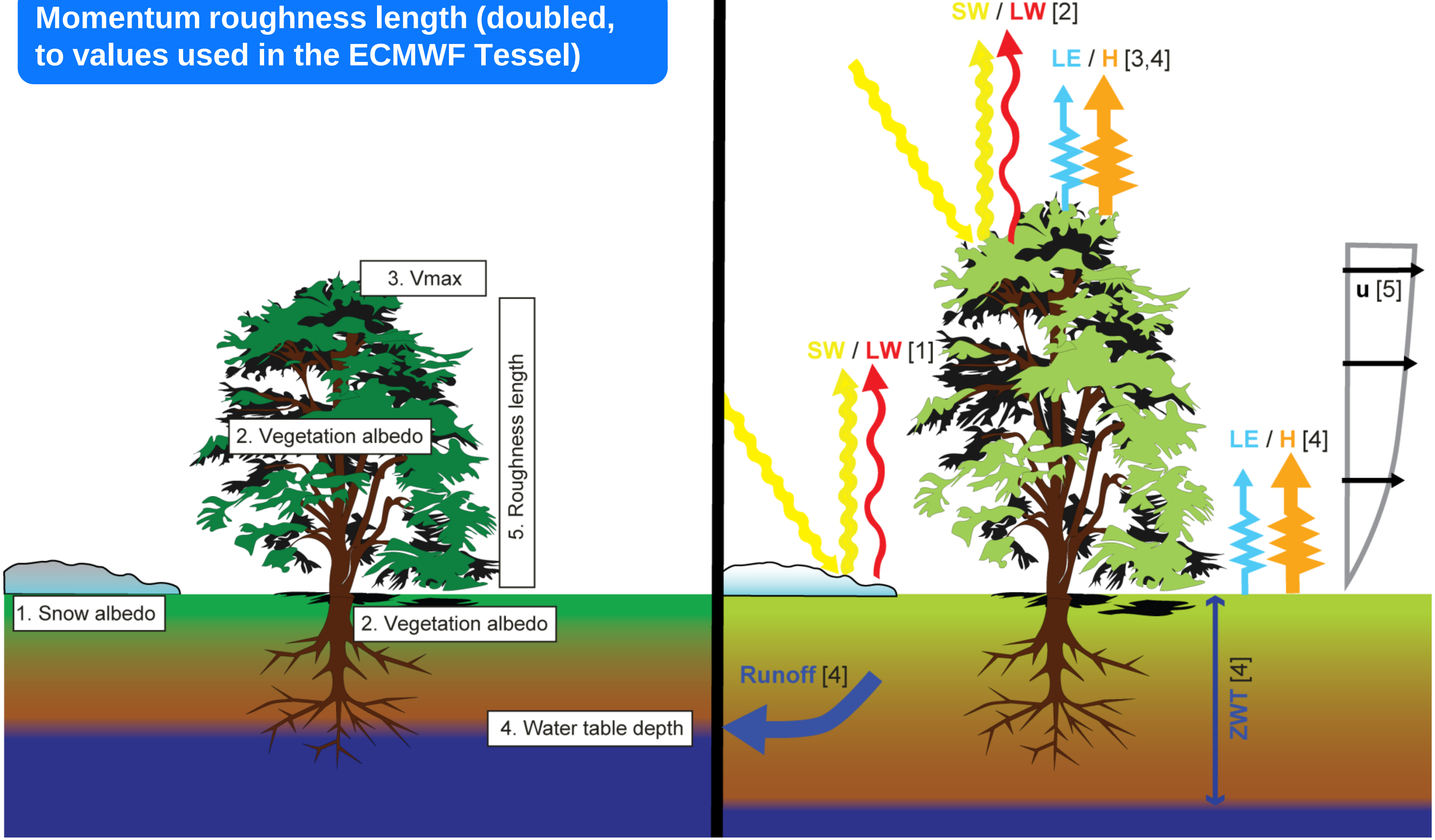
Control

Perturbed

Momentum roughness length (doubled, to values used in the ECMWF Tessel)



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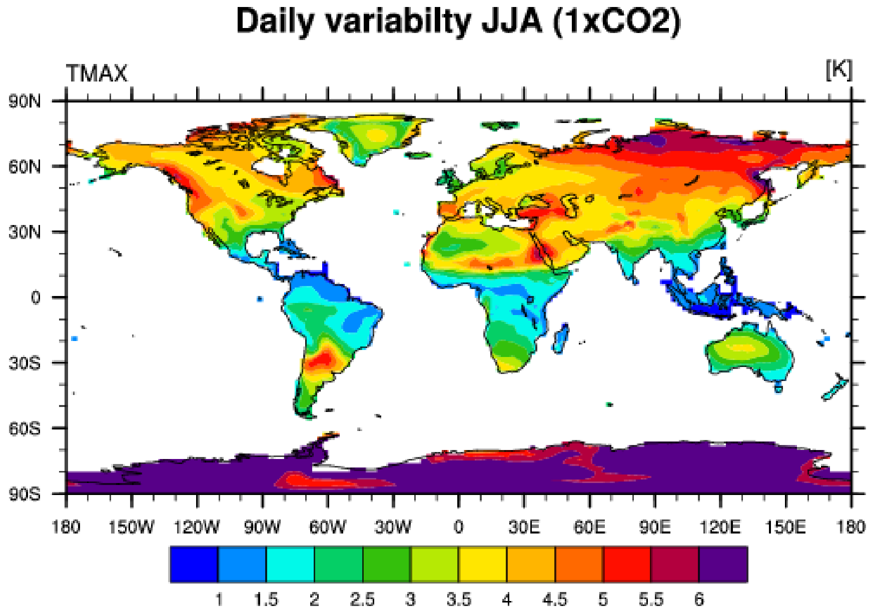
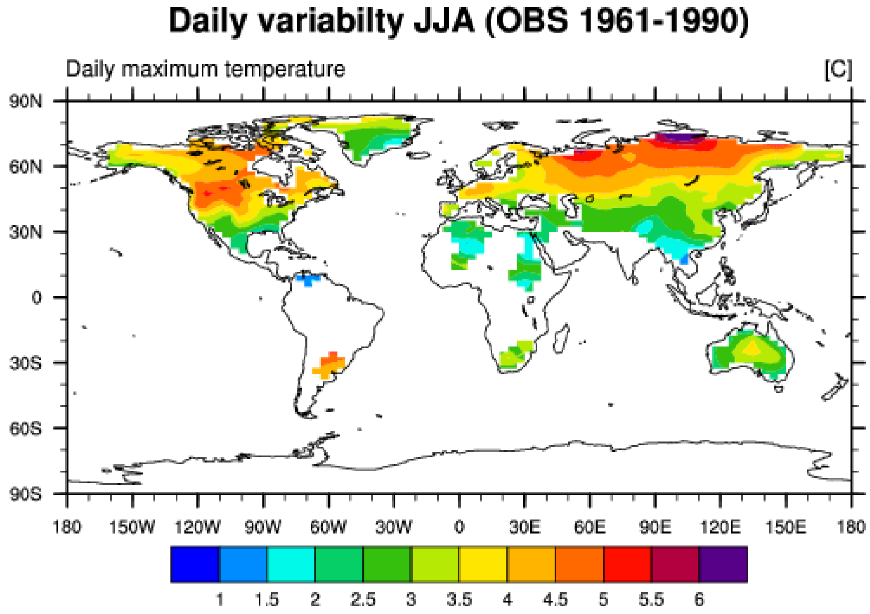
How well is variability simulated in CCSM3.5?





Overestimation over middle East

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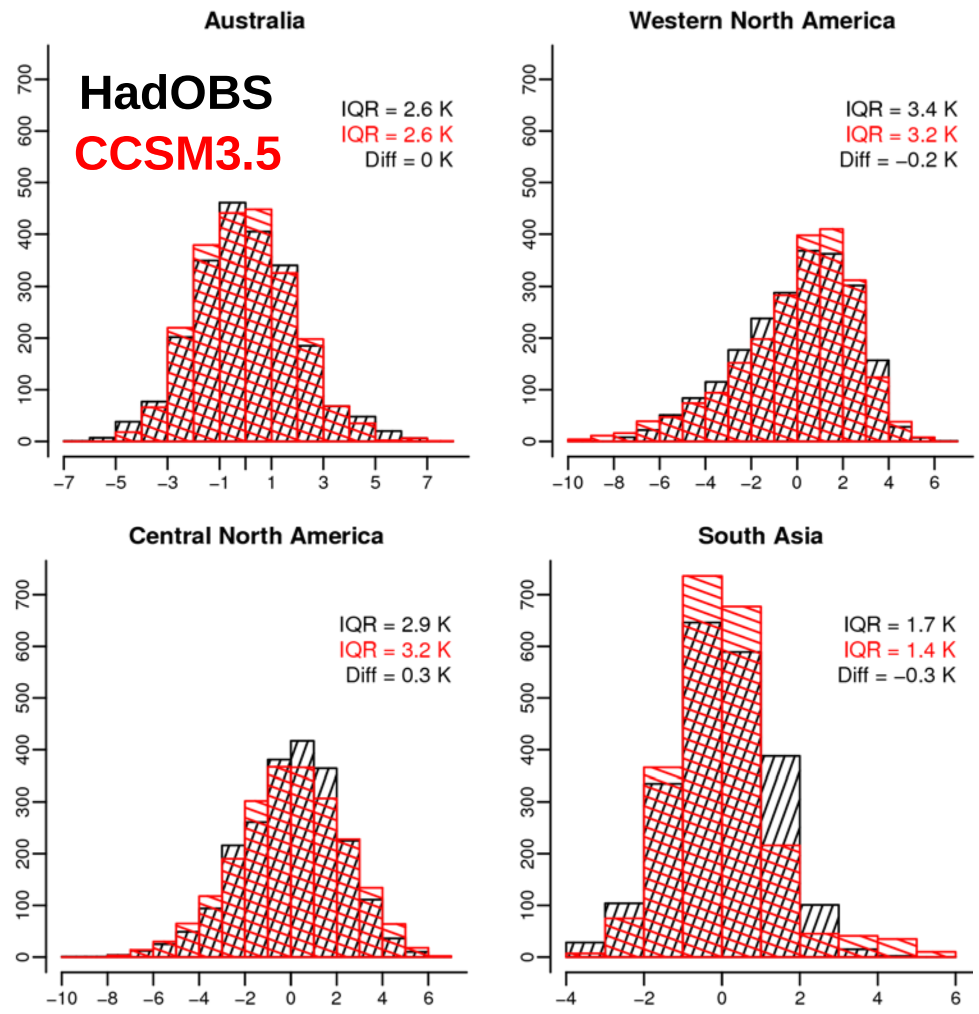
How well is variability simulated in CCSM3.5?



Scale and shape of distribution are remarkably well captured

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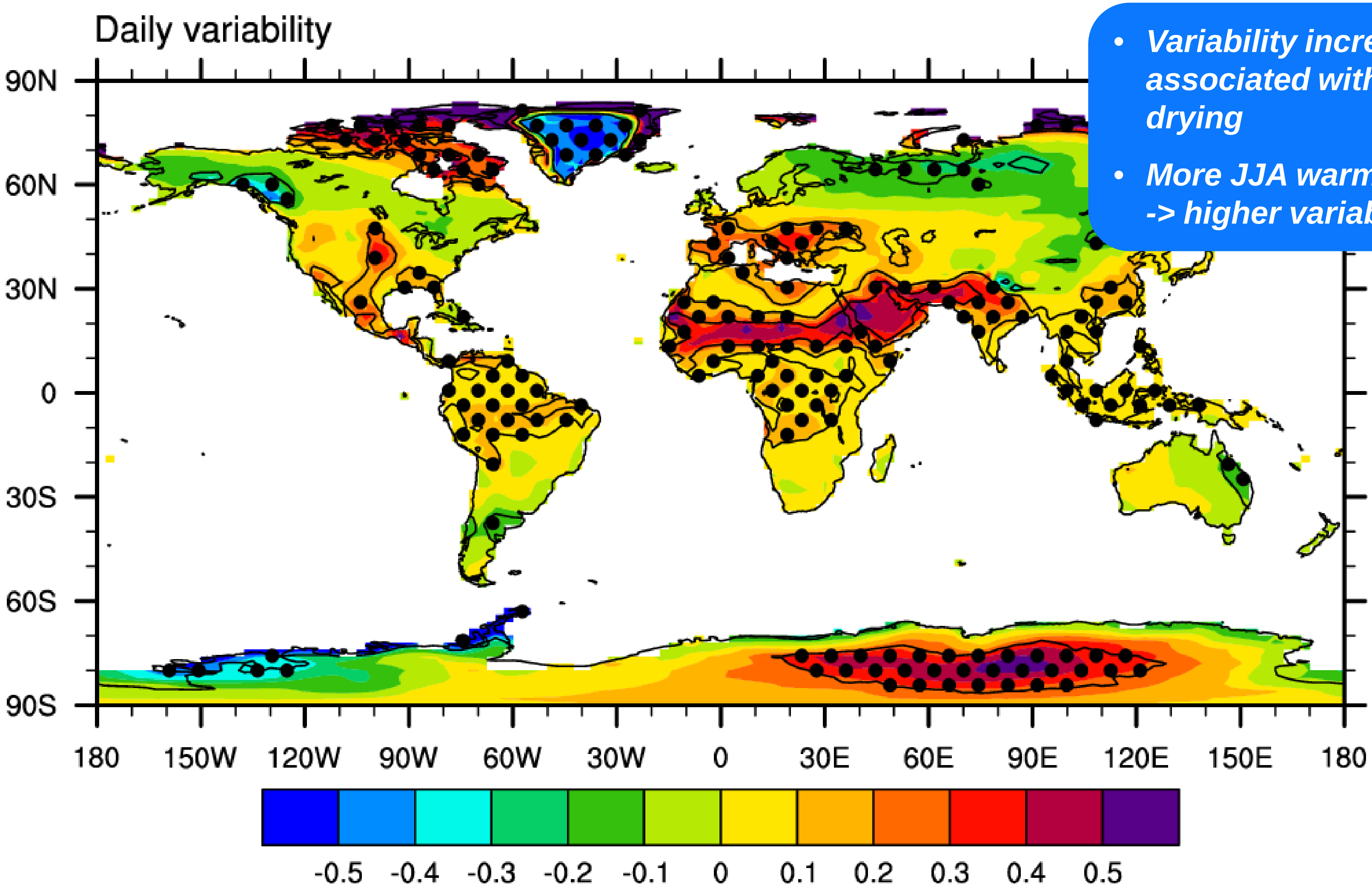
JJA variability response to $2xCO_2$



- *Variability increase associated with soil drying*
- *More JJA warming -> higher variability*

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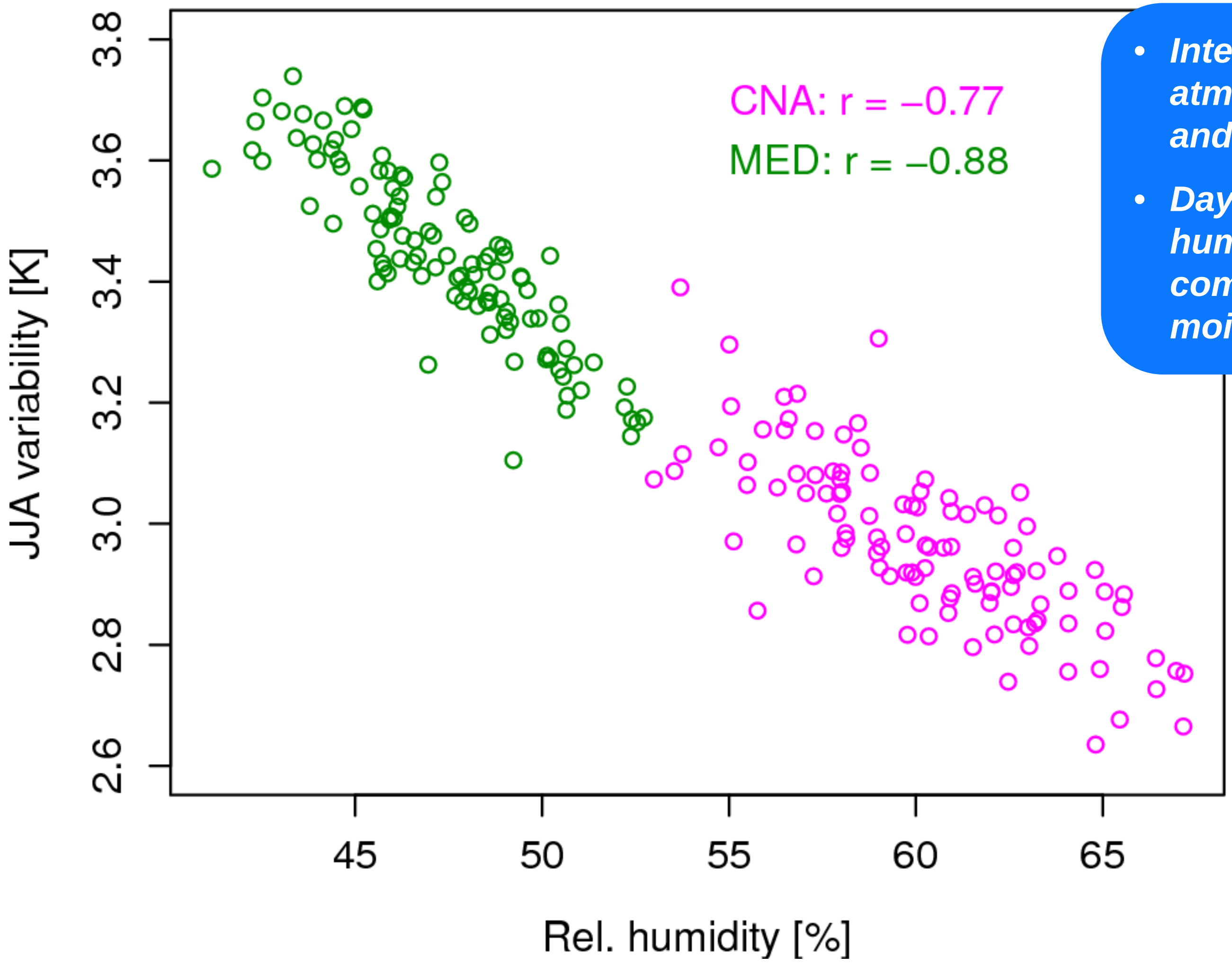
What mechanisms are driving JJA variability?



- ***Interannual var: atmospheric circulation and soil moisture***
- ***Day-to-day var: Relative humidity points to a combined effect of moisture and temperature***

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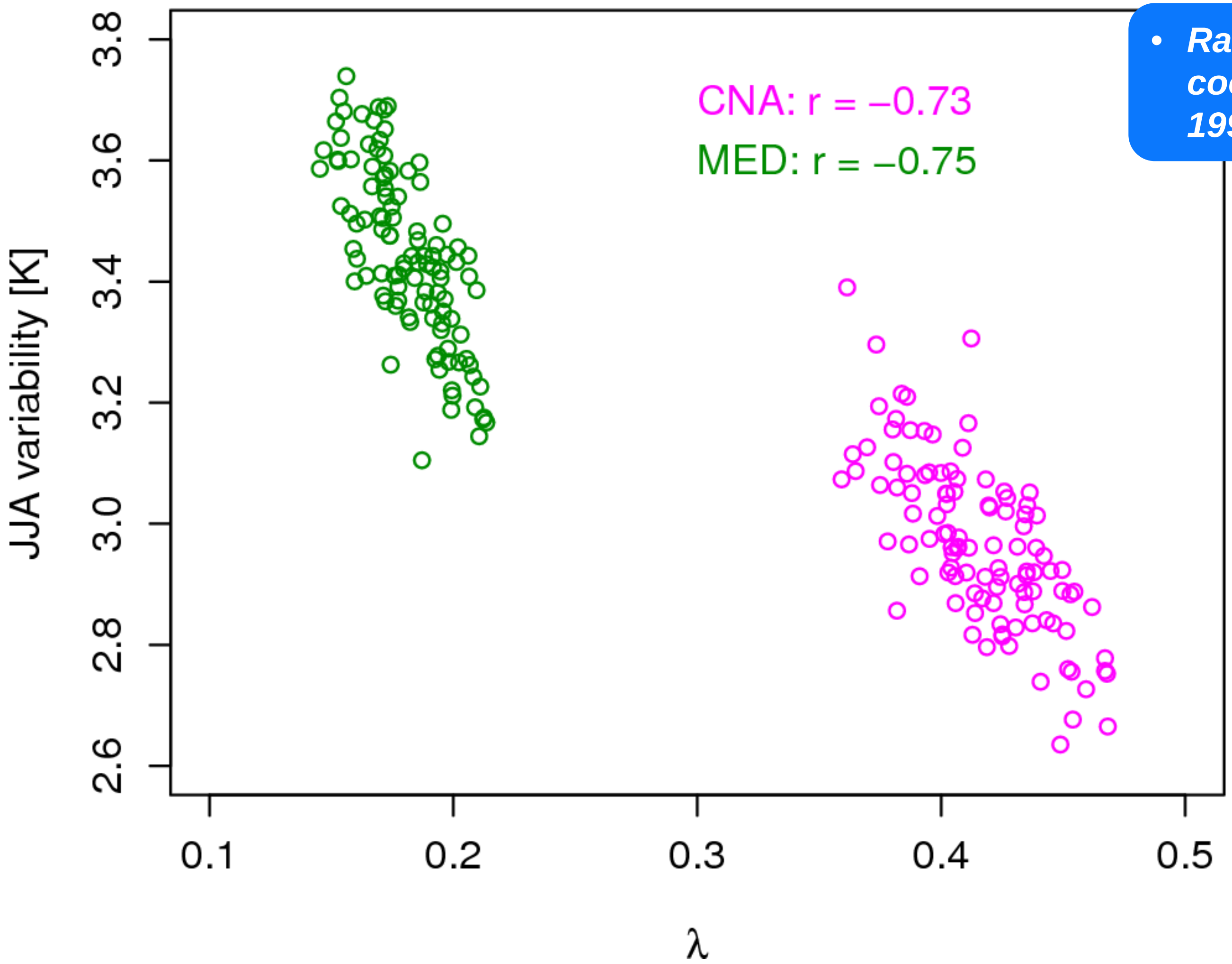
Latent cooling as a damping factor



- ***Ratio of latent to radiative cooling (Gregory et al. 1995)***

$$\lambda = \frac{LE}{LE + H + LW}$$

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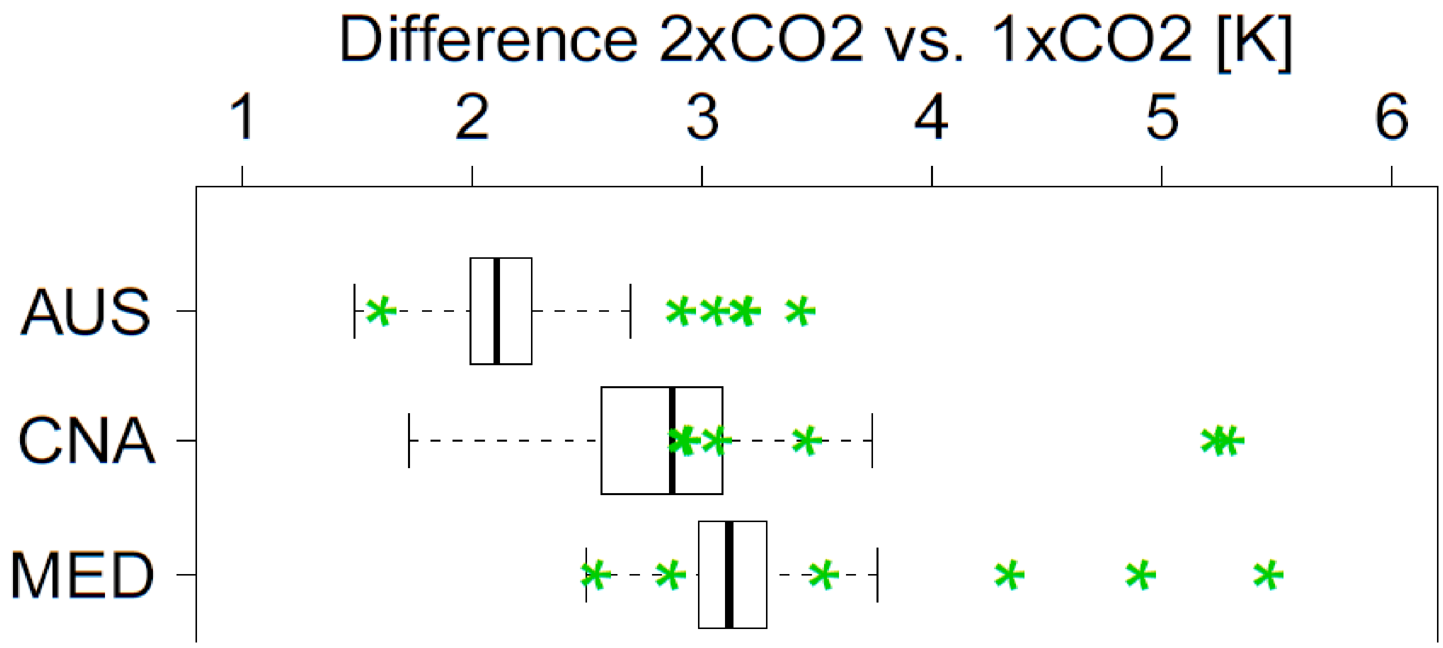
Hot extremes (Summer 95th percentile)



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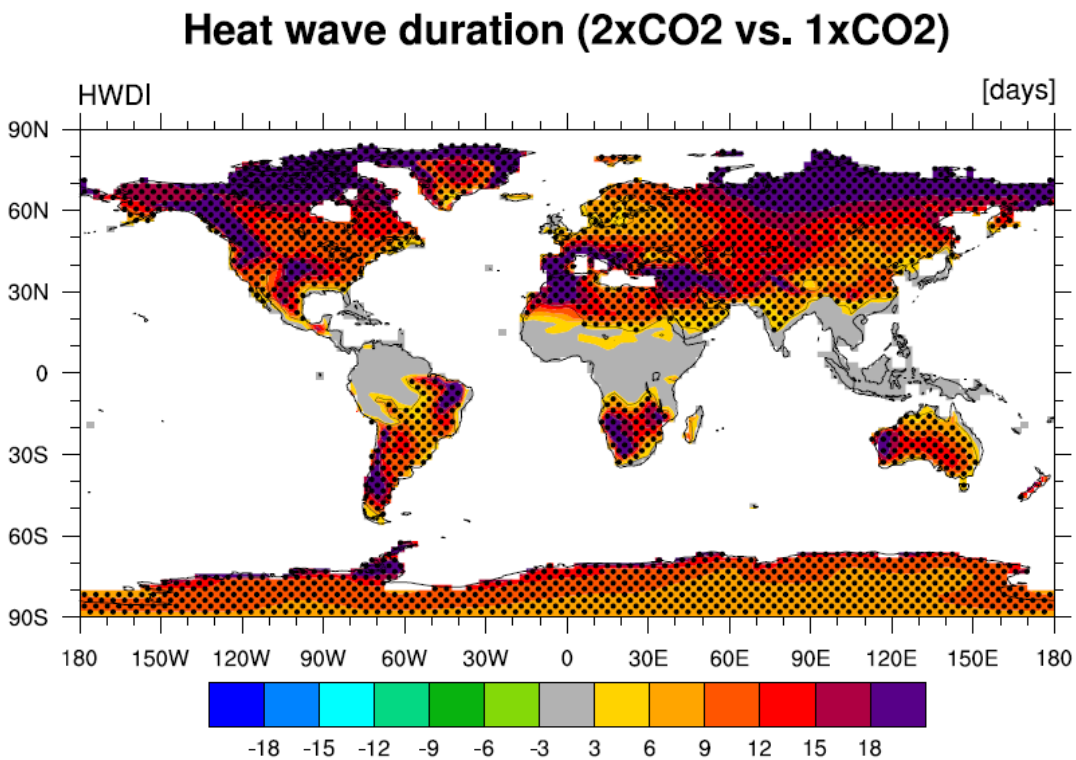
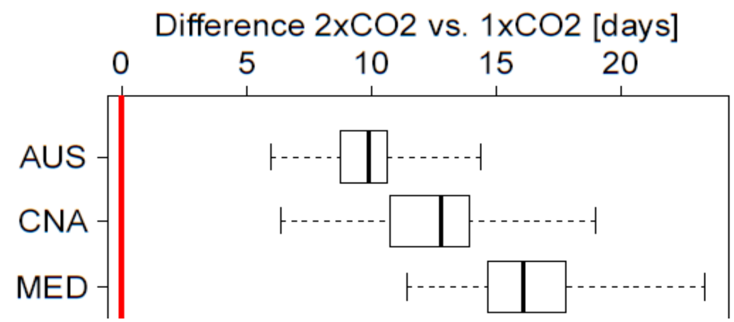
Heat wave duration in summer half-year



- *Large uncertainties due to 2 uncertain variables*



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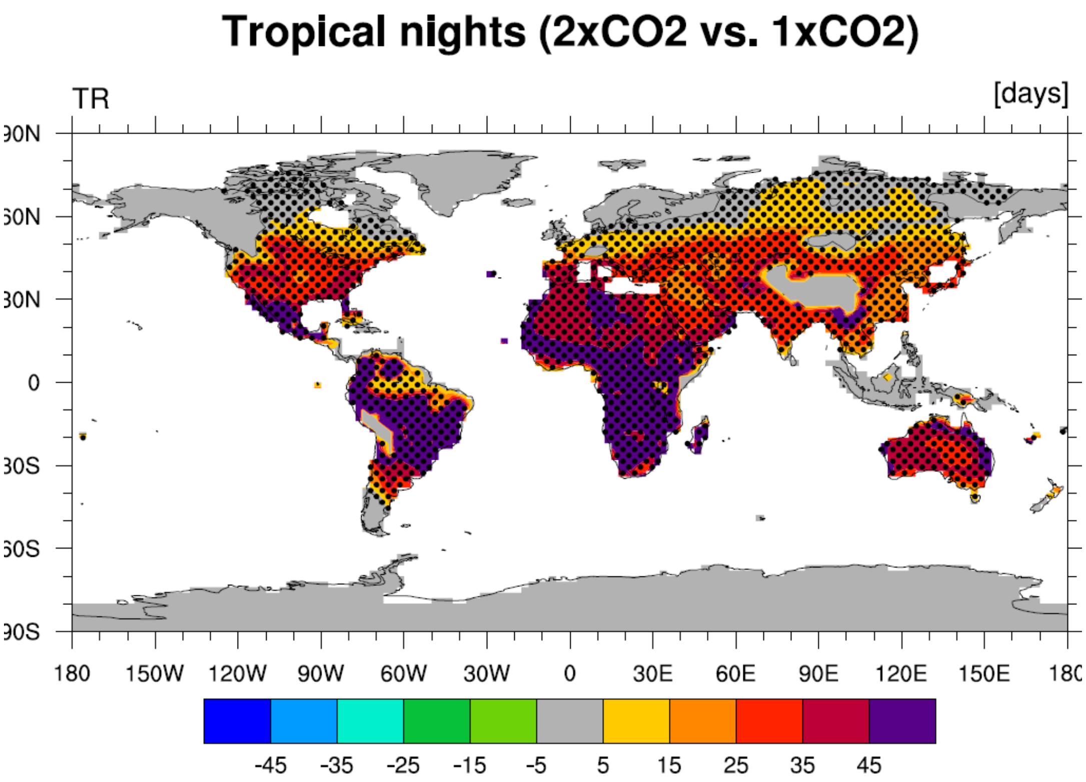
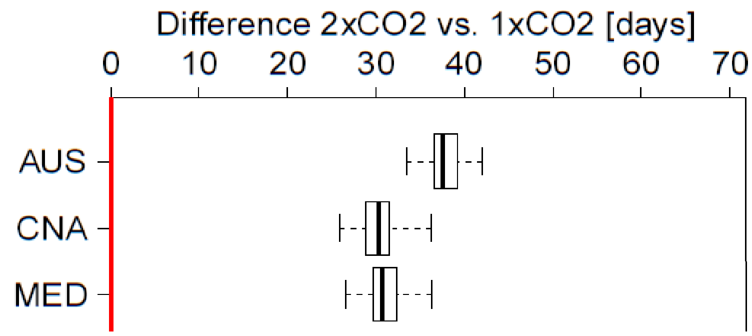
Number of tropical nights



- *Small sensitivity of night-time temperatures to land surface parameters*



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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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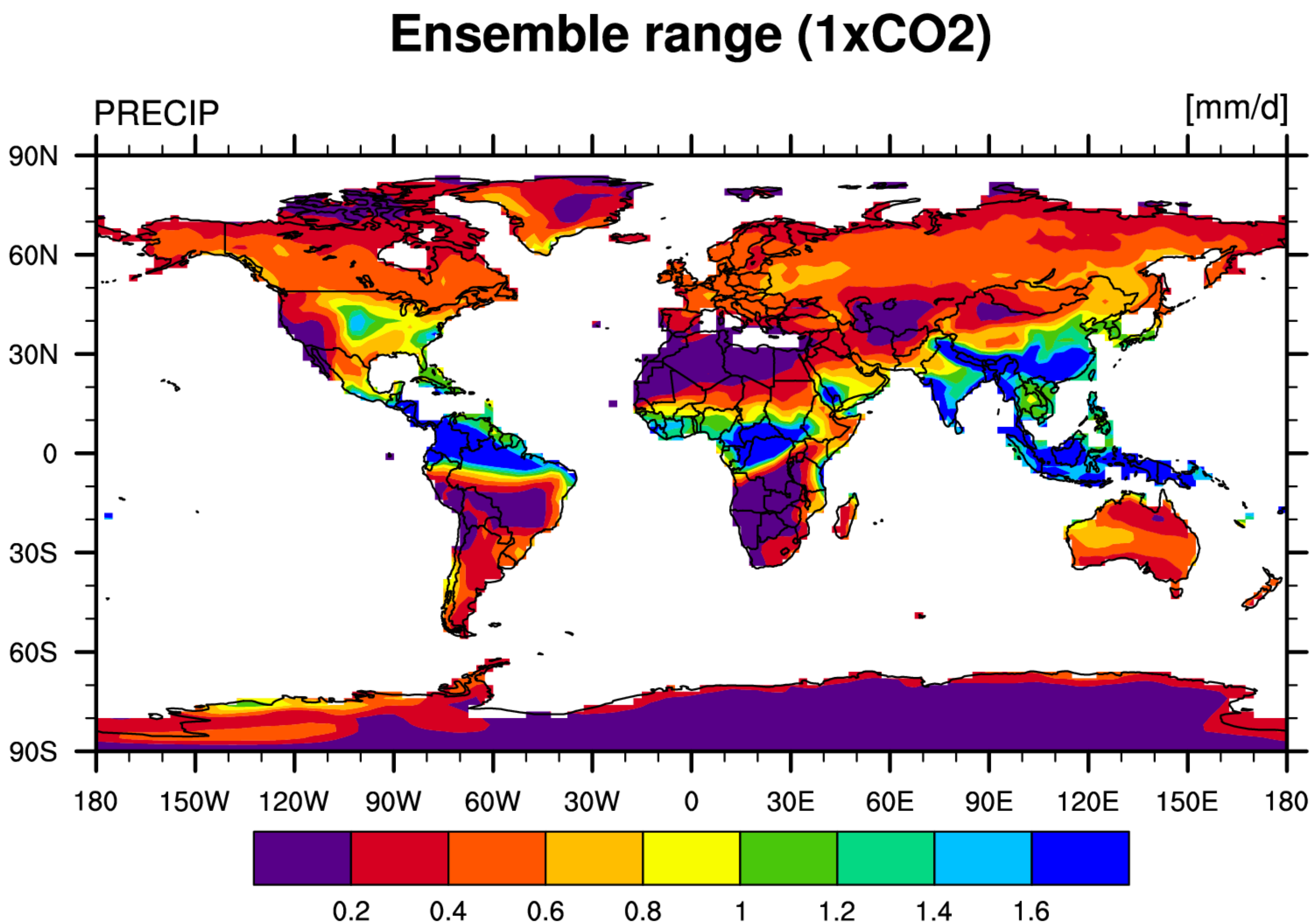
Ensemble range for JJA precipitation



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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

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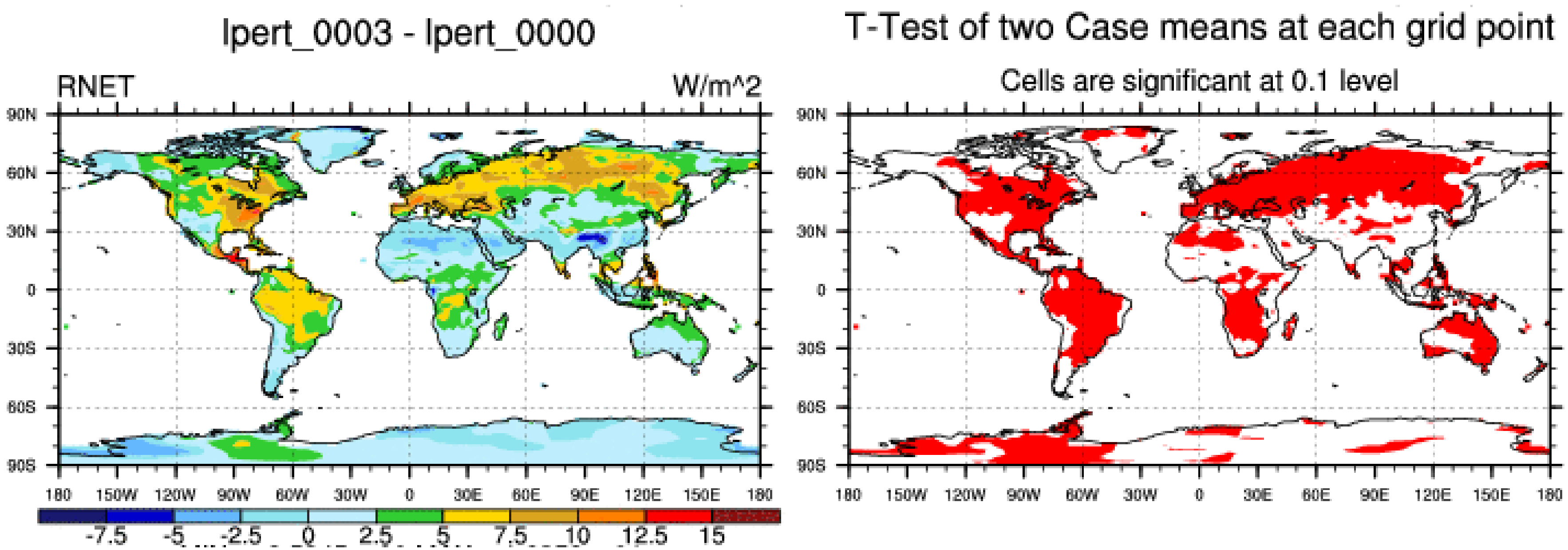
Low veg. albedo vs. CTL (JJA)



Annual global land energy budget:
net radiat.: **+2.0 W/m²**
latent heat: **+0.7 W/m²**
sensible heat: **+1.3 W/m²**

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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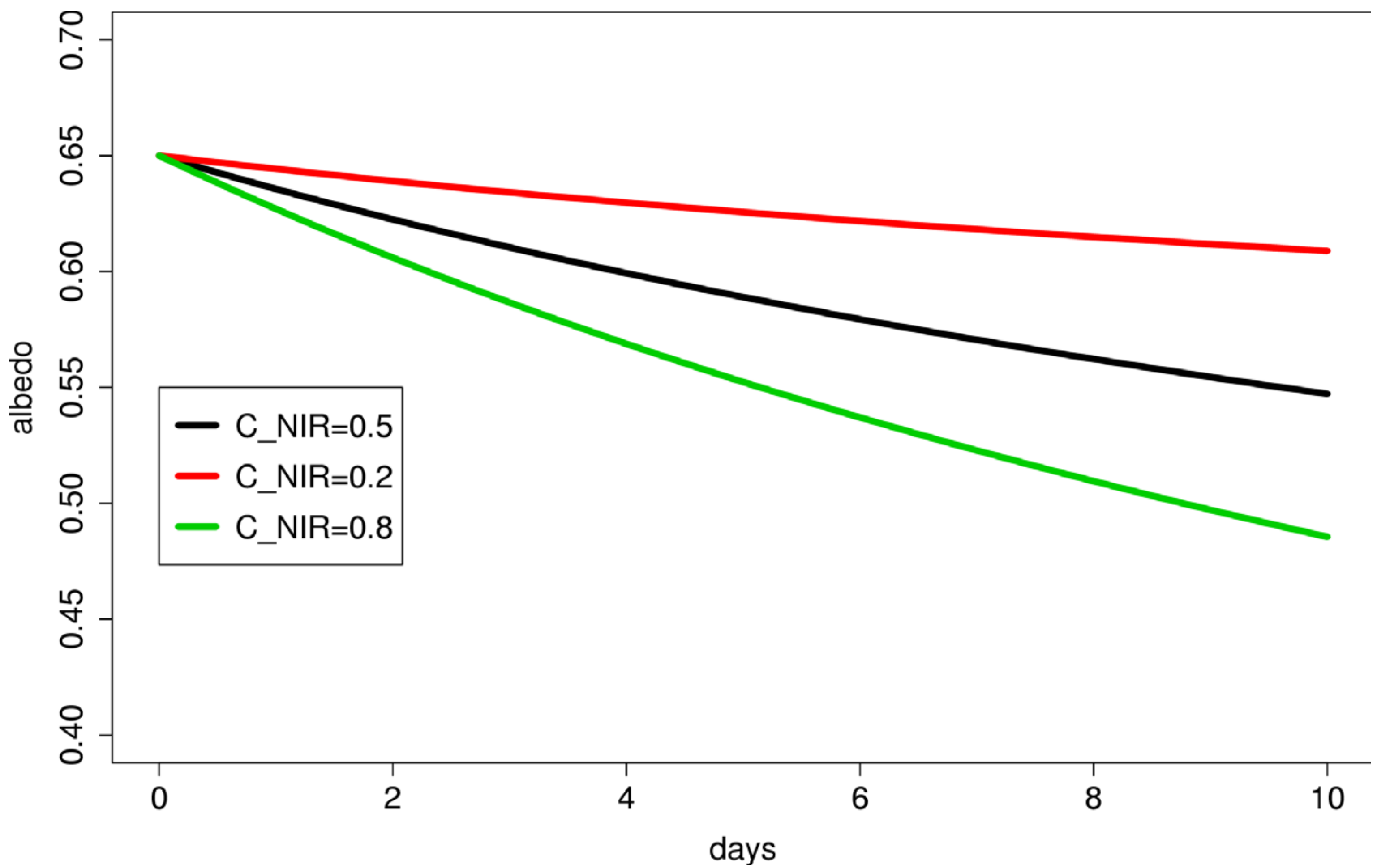
Snow albedo (near-infrared) – snow aging



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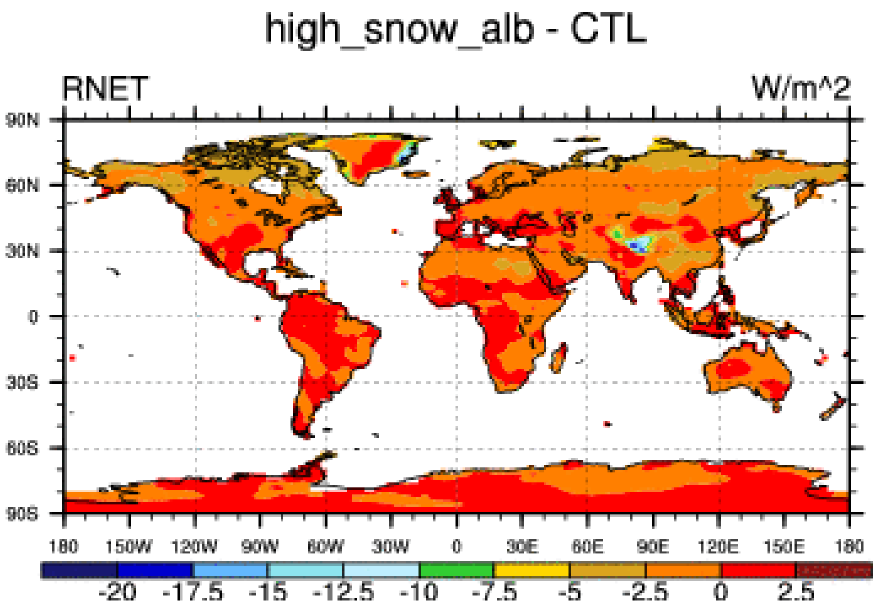
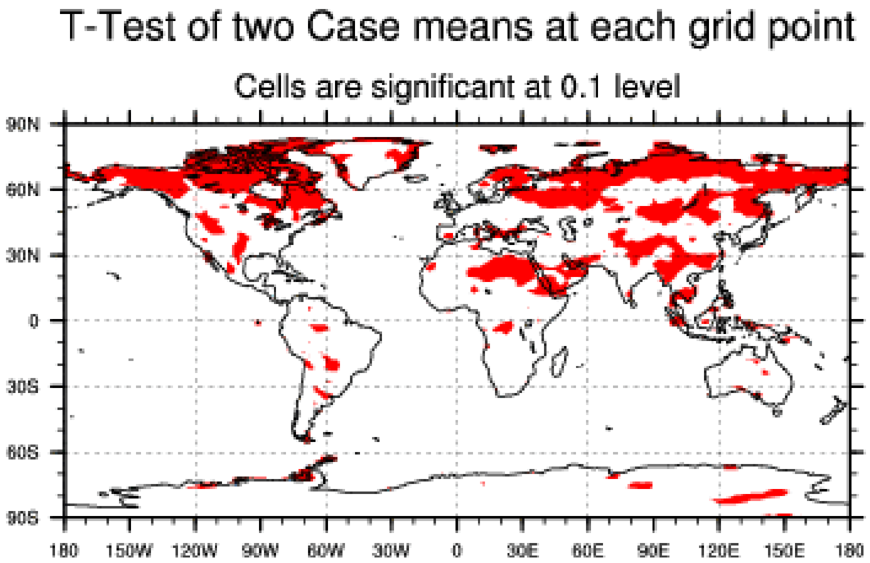
Snow albedo – snow aging





Global land net radiation -0.64 W/m^2

Effects strongest in spring and over Tibetan Plateau

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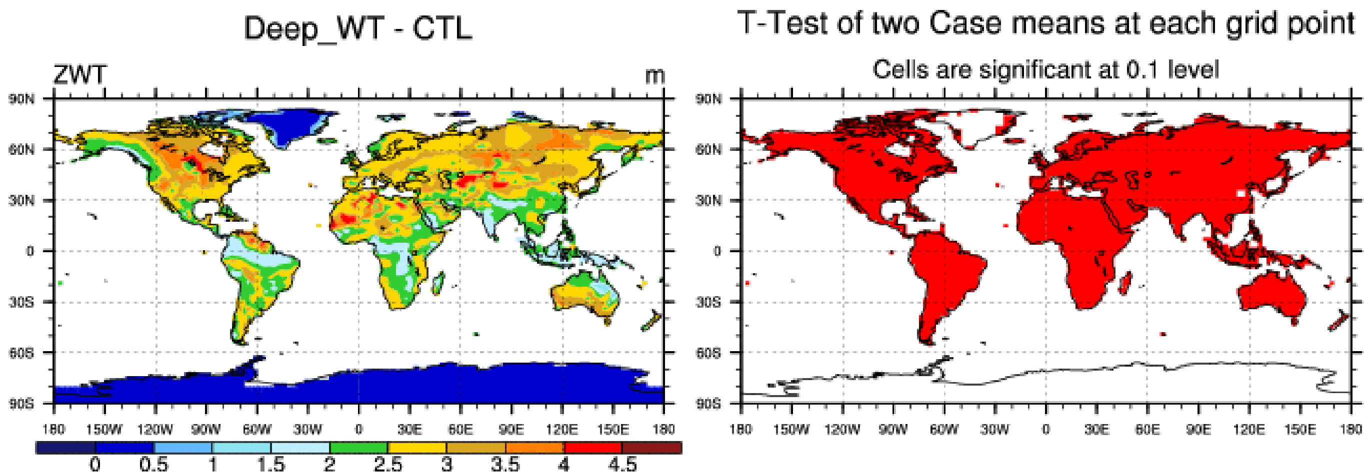
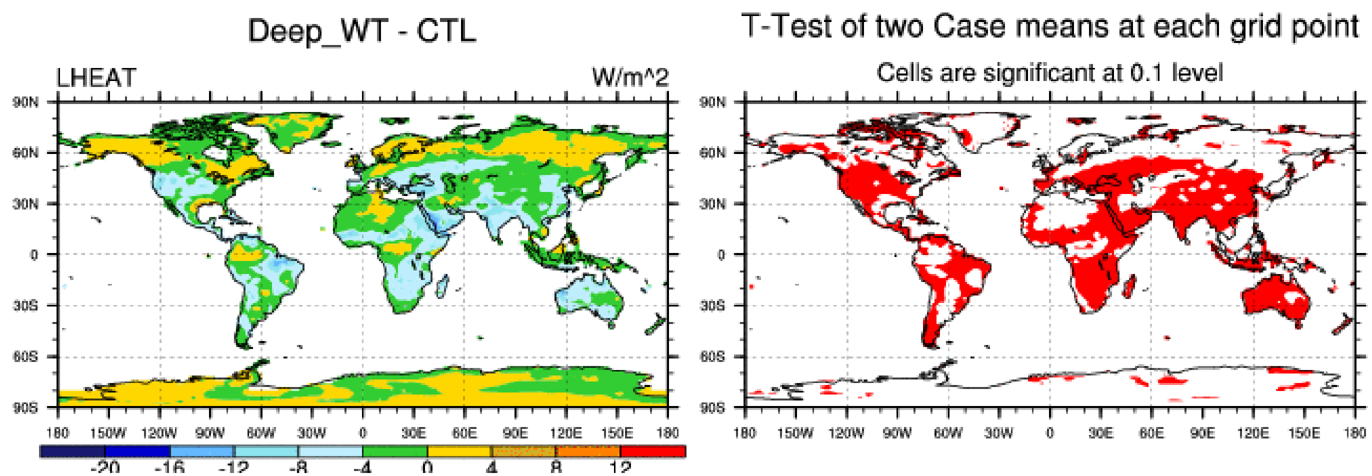
Decay factor affecting water table depth

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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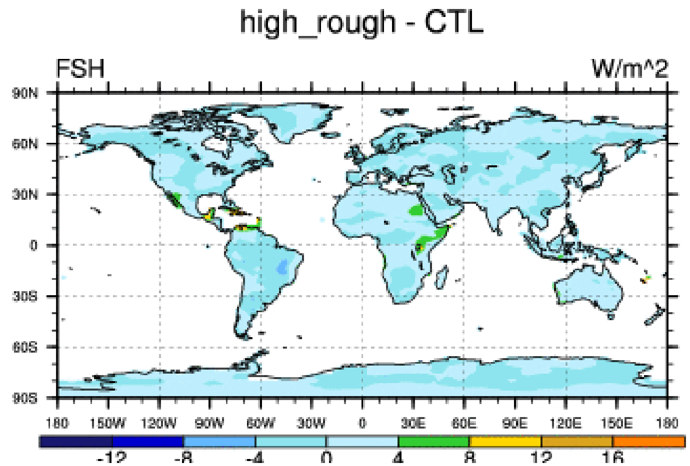
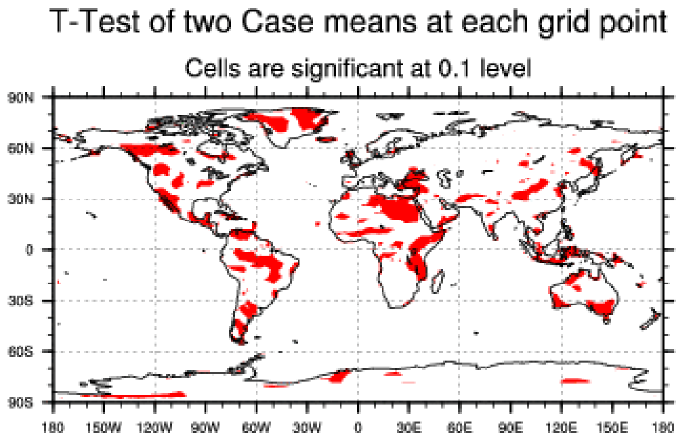
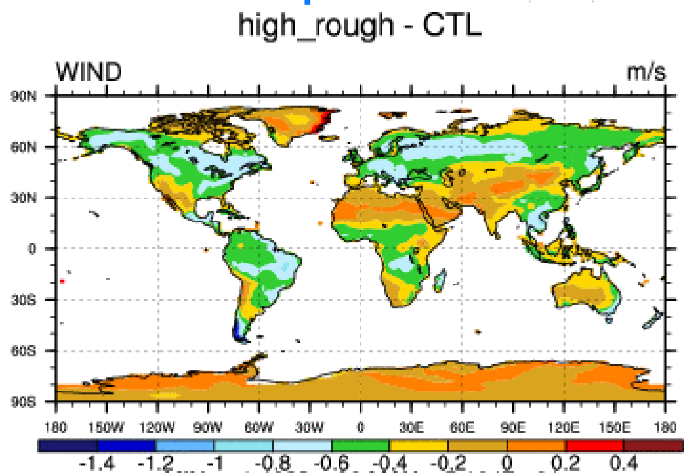
Roughness length

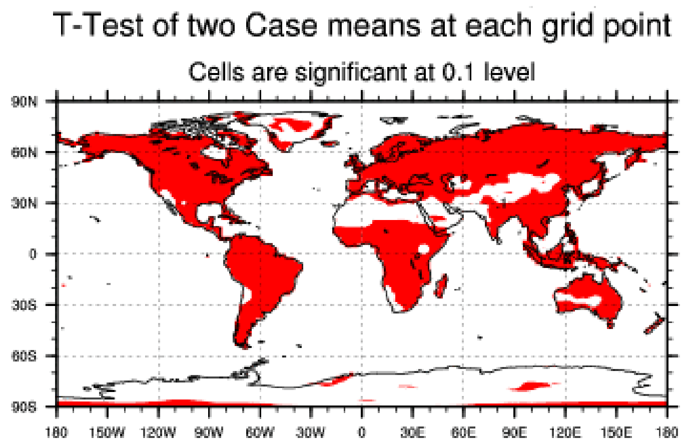
Sensible heat flux





Mean wind speed





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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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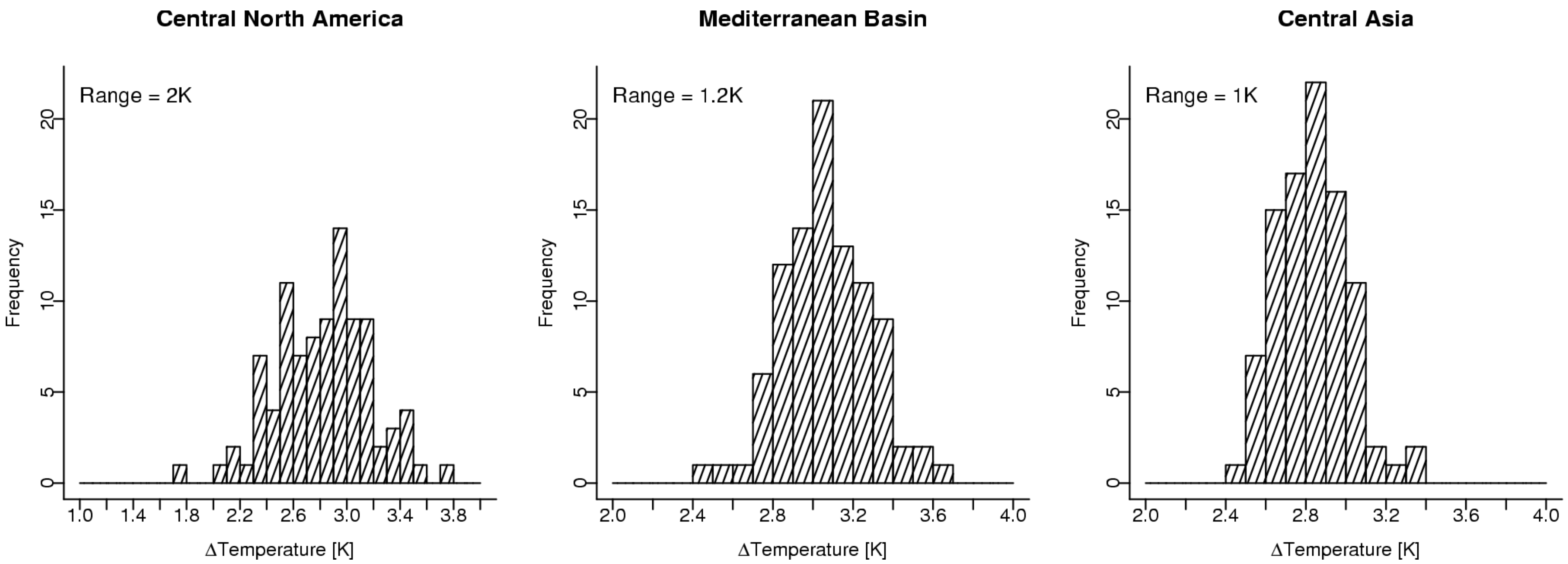
Regional change of 95th perc. (JJA)



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

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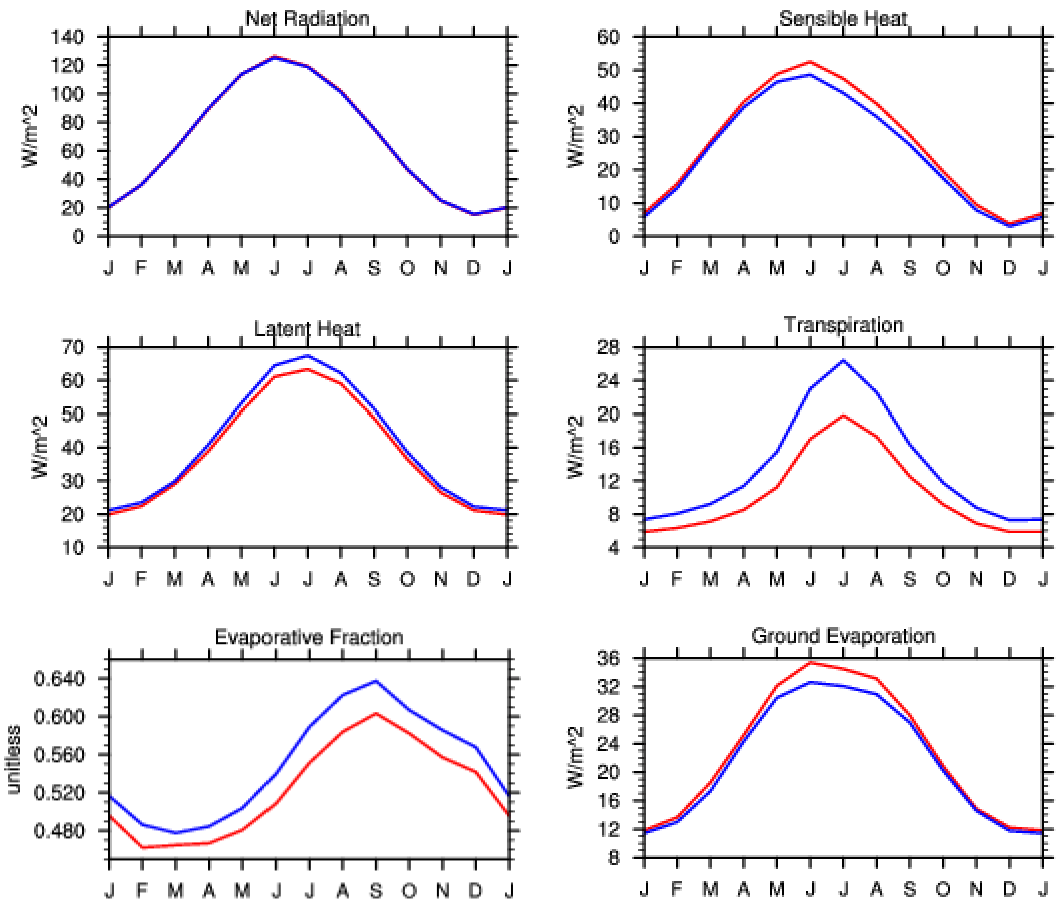
V_{cmax} (perturbed vs. CTL)

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



Annual global energy budget:

latent heat	**-1.95W/m^2**
transpiration	**-3.76W/m^2**
ground evap.	**+1.70W/m^2**
sensible heat	**+2.11W/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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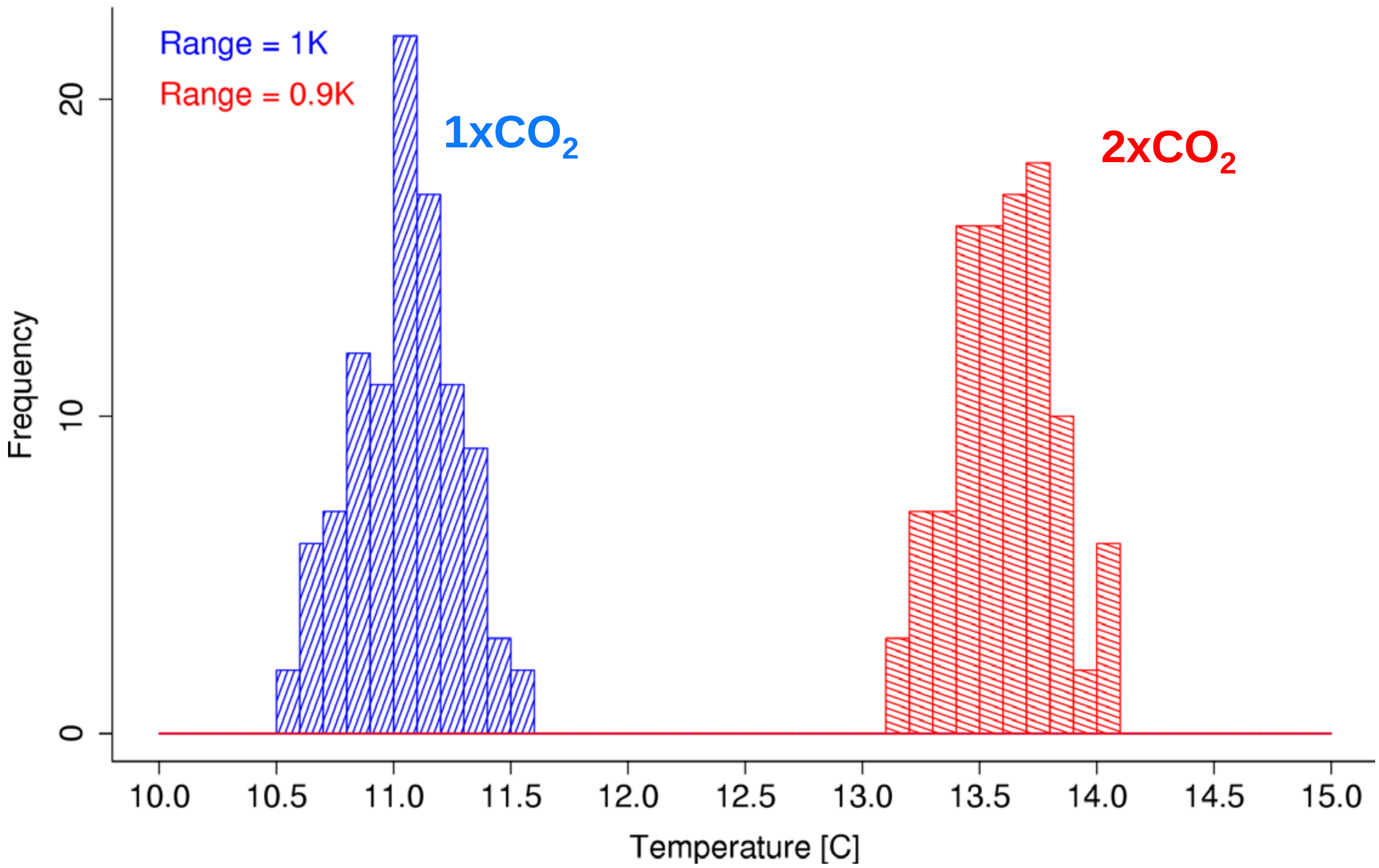
Global annual land temperature



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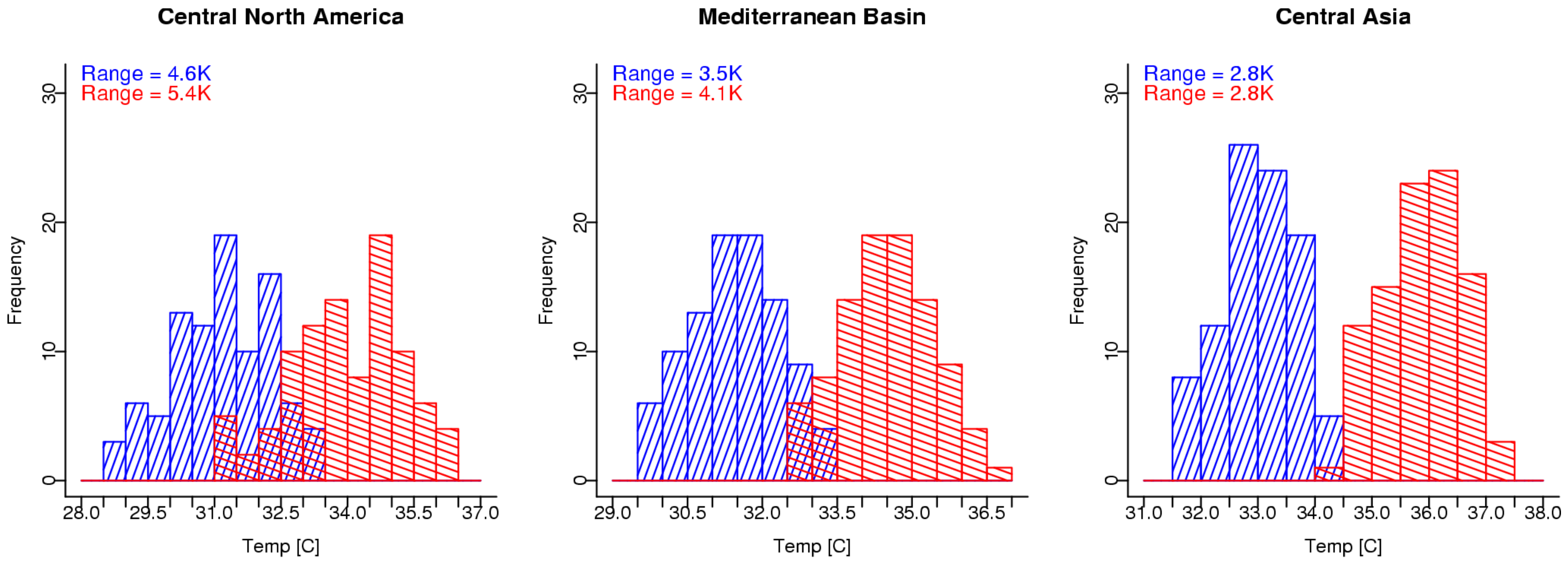
95th percentile of daily JJA temperatures



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

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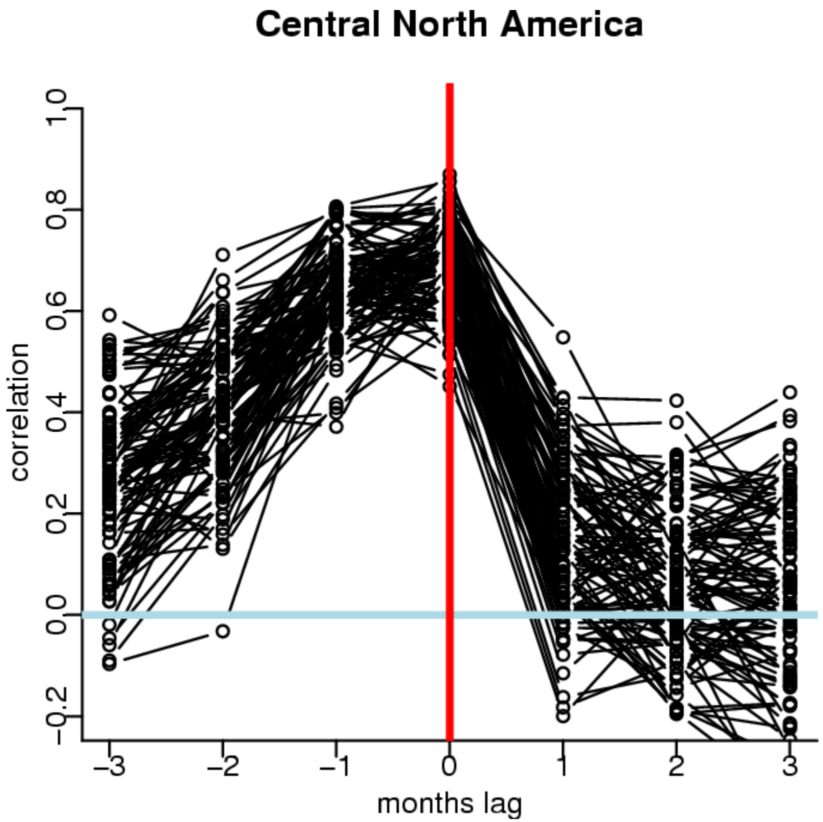
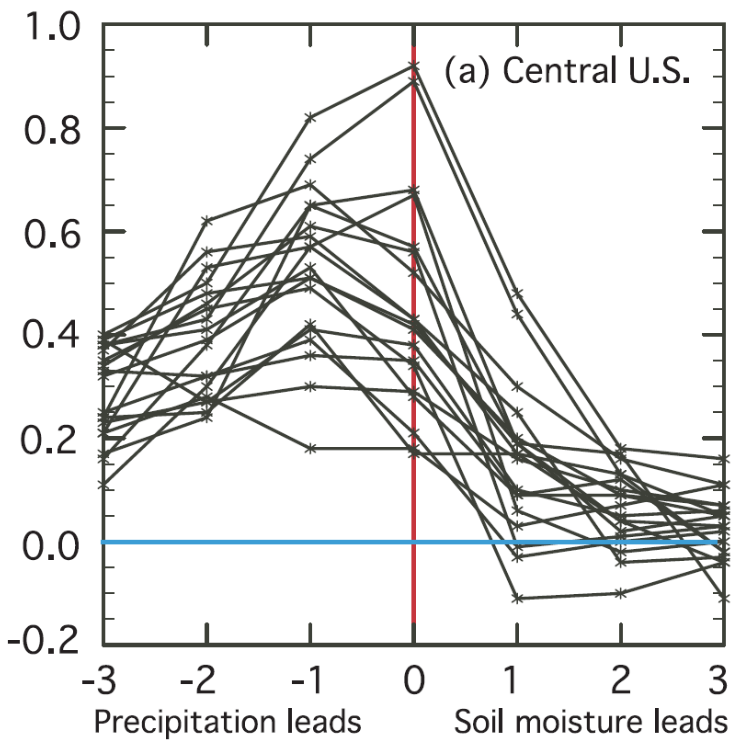
Coupling CLM pert. exp. vs. CMIP3



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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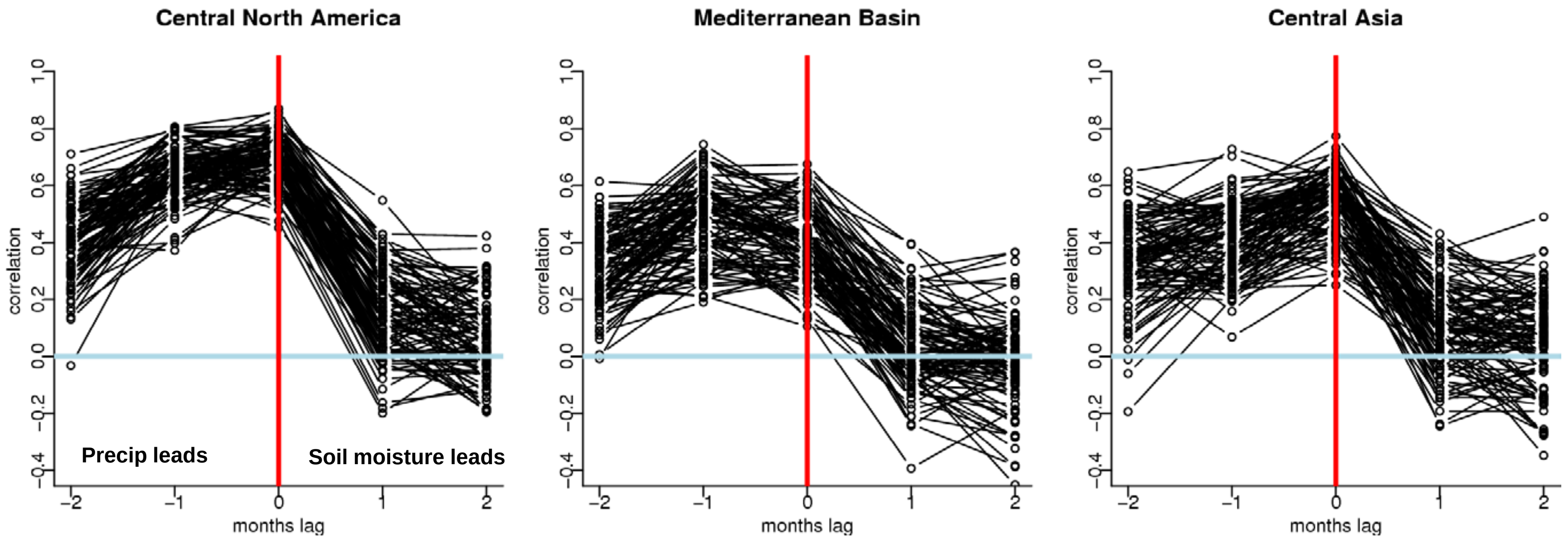
Soil moisture-precipitation coupling



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