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A standard climate sensitivity experiment for black carbon aerosols

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A standardized global climate model study showing unique properties for the climate response to black carbon aerosols

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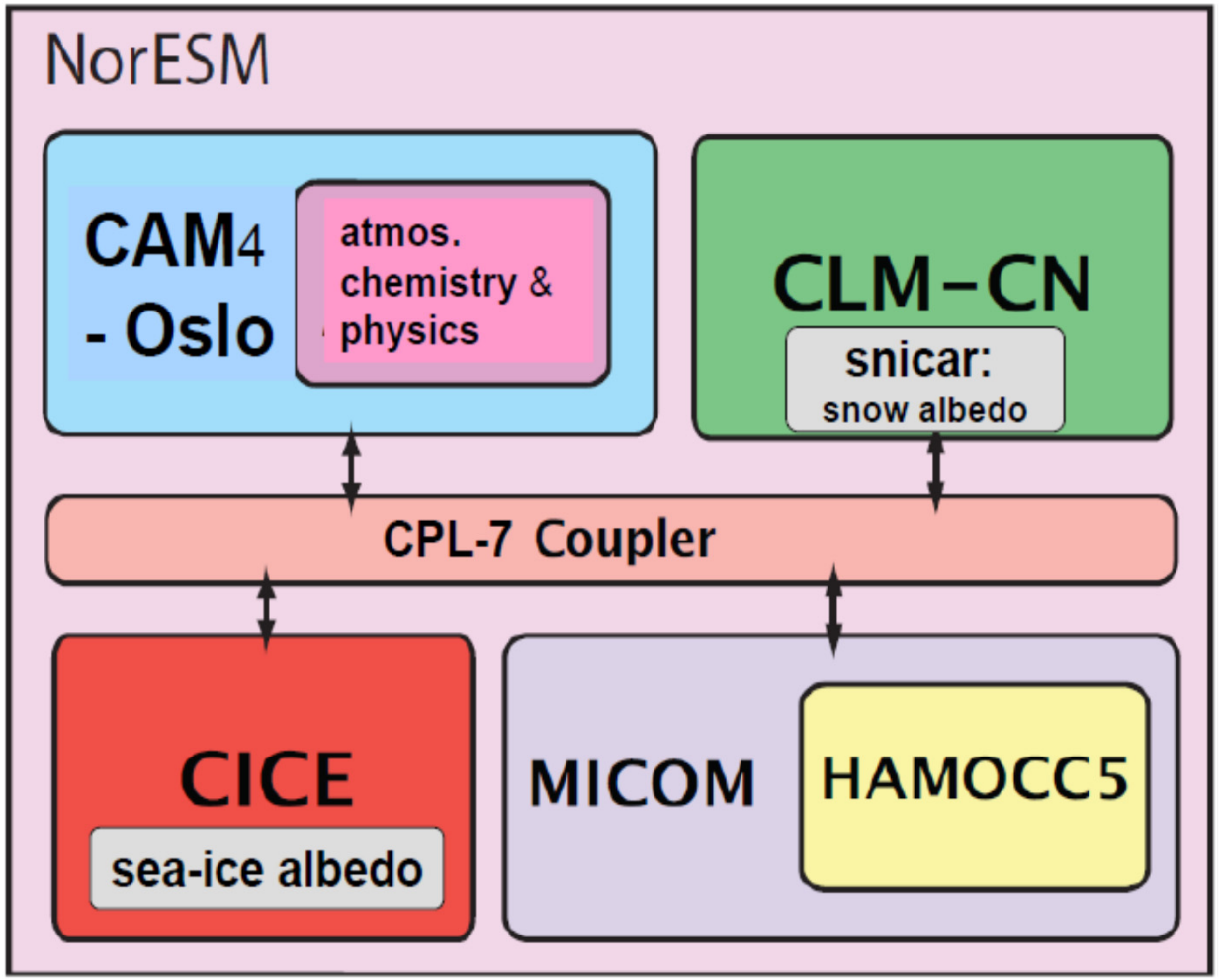
NorESM
components and interactions



Equilibrium Climate Sensitivity (ECS):

The global surface air temperature change (ΔT_s) in response to an abrupt TOA radiative forcing (ΔR_0) introduced to a climate in equilibrium, evaluated when a new TOA radiative equilibrium is reached.

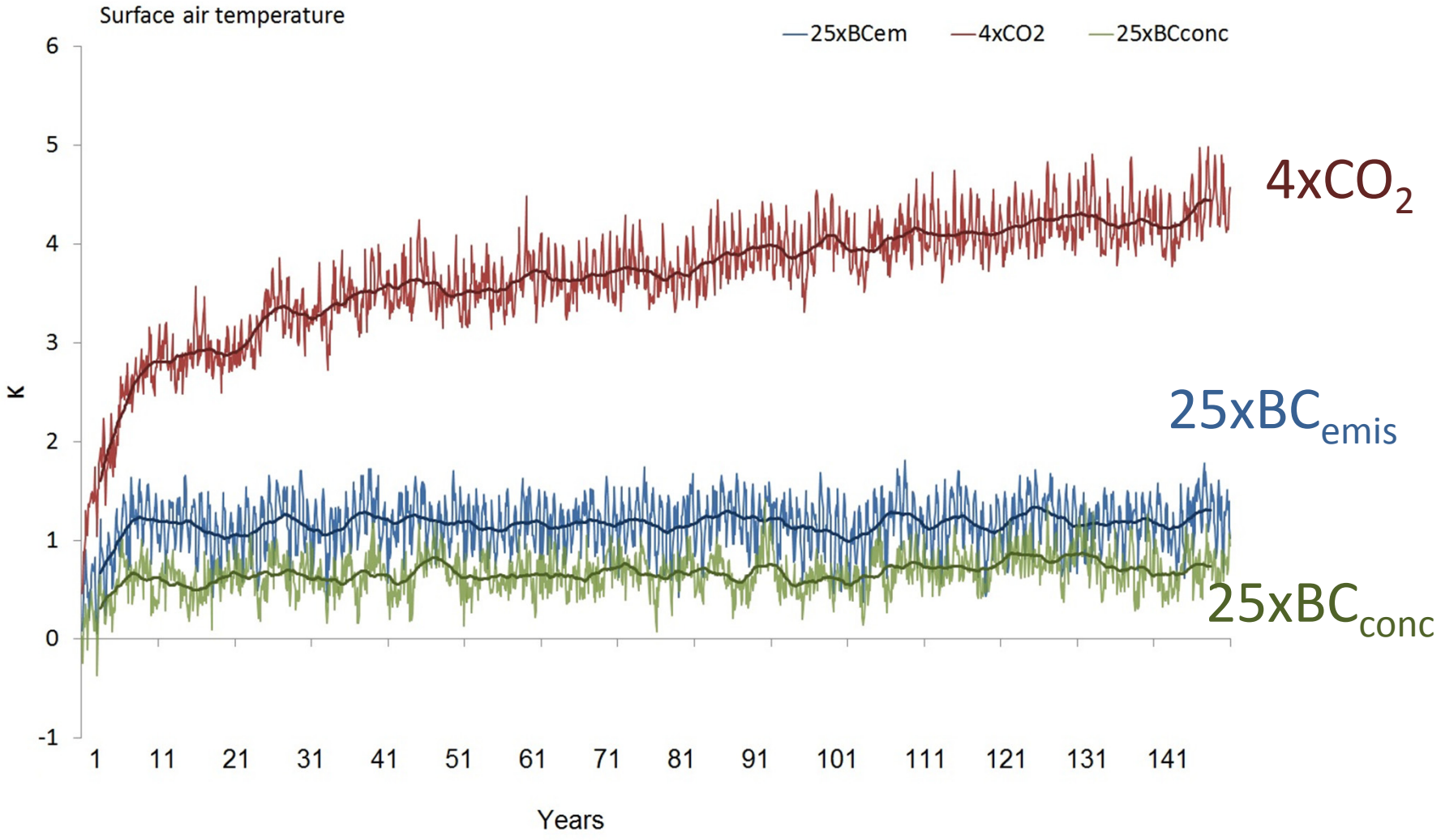
- CTRL: pre-industrial (1850) control in balance
- 4xCO_2: 4x pre-ind. atmospheric CO_2 conc. ($\Delta R_0 \approx 7 Wm^{-2}$)

New:

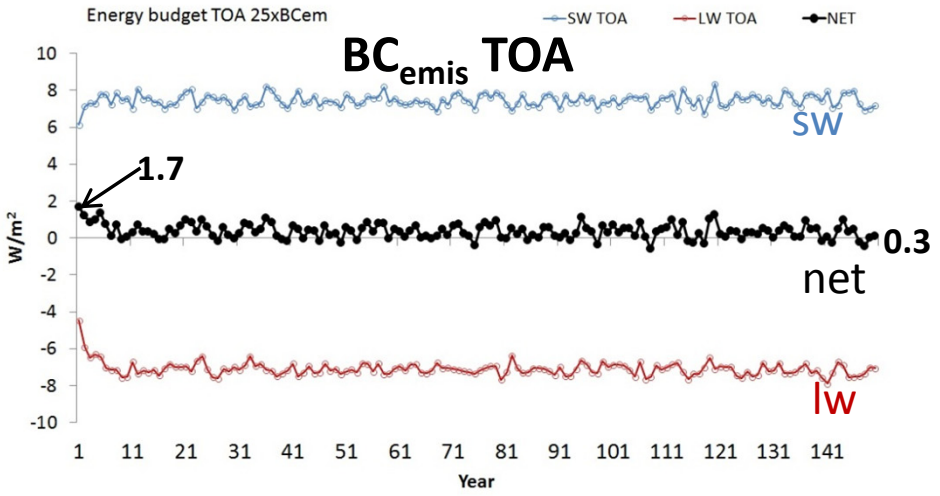
- 25xBC_{emis}: 25xQ_{emis}**(2000 fossil+biofuel)** ($\Delta R_0 \approx 7.3 Wm^{-2}$)
- 25xBC_{conc}: prescribed perpetual annual cycle of BC-conc. produced off-line using 25xQ_{emis} **(2000 fossil+biofuel)**

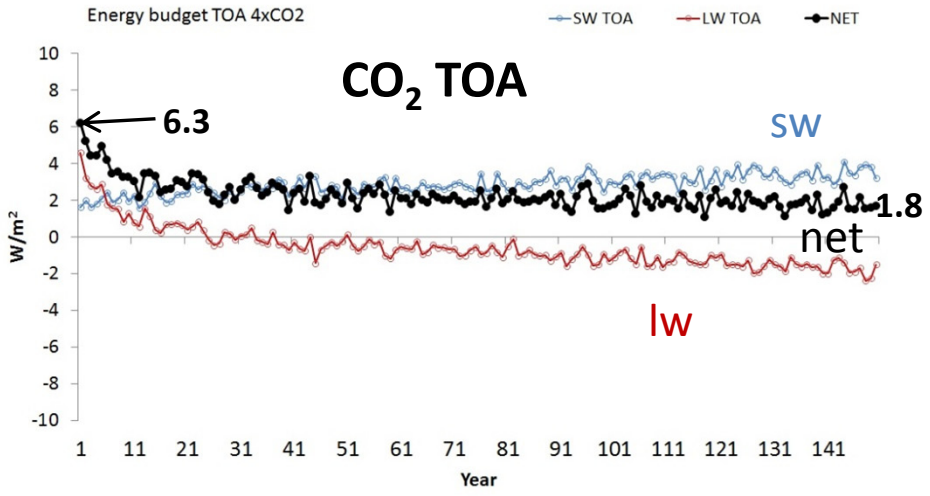
$$\Delta R_0 = \lambda \, \Delta T_s \; ; \; ECS = 1/\lambda$$

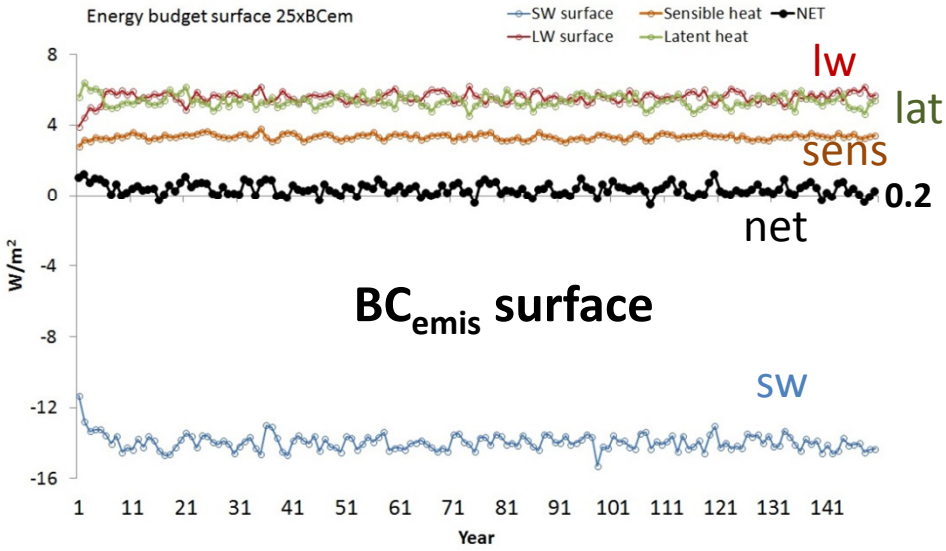
Global surface temperature response

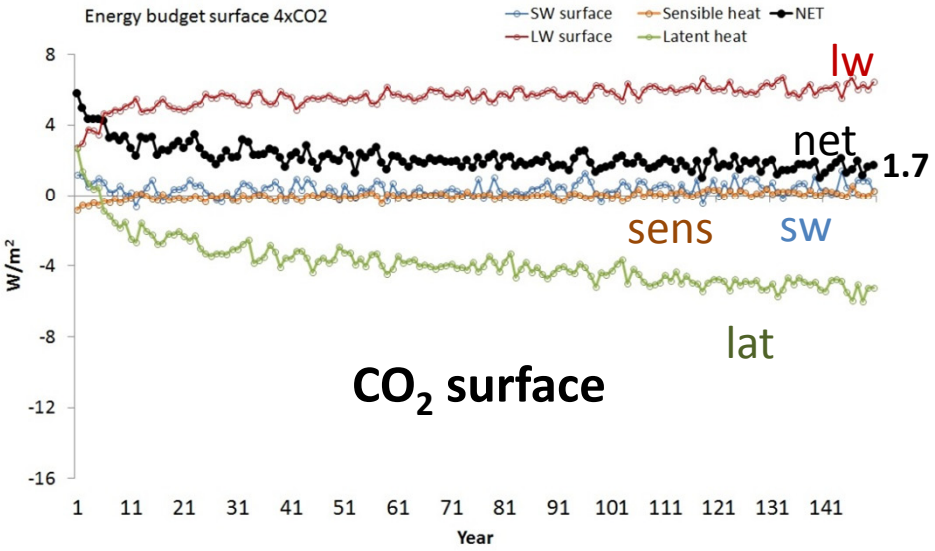


Energy Budgets: *Annual values*

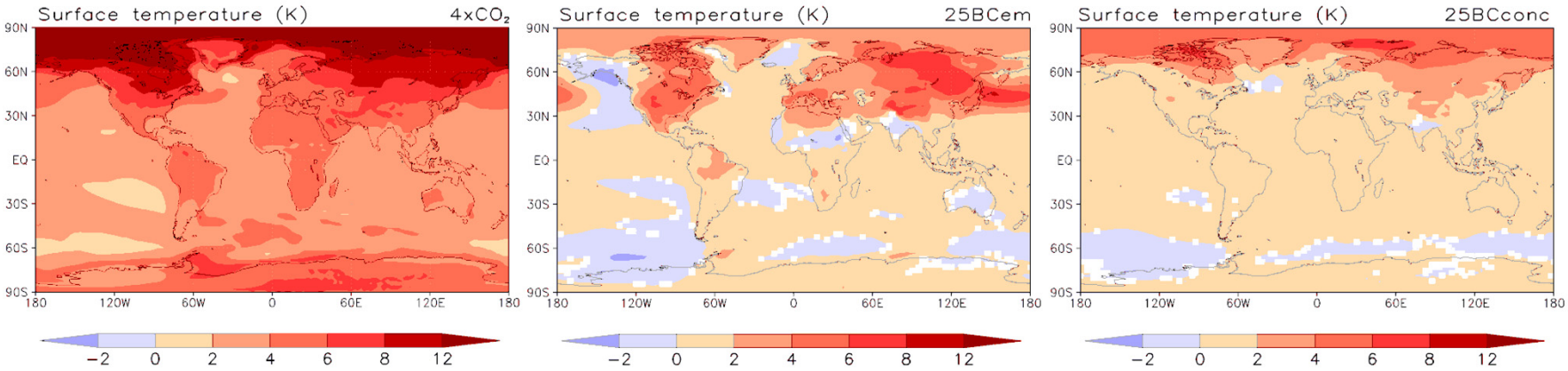






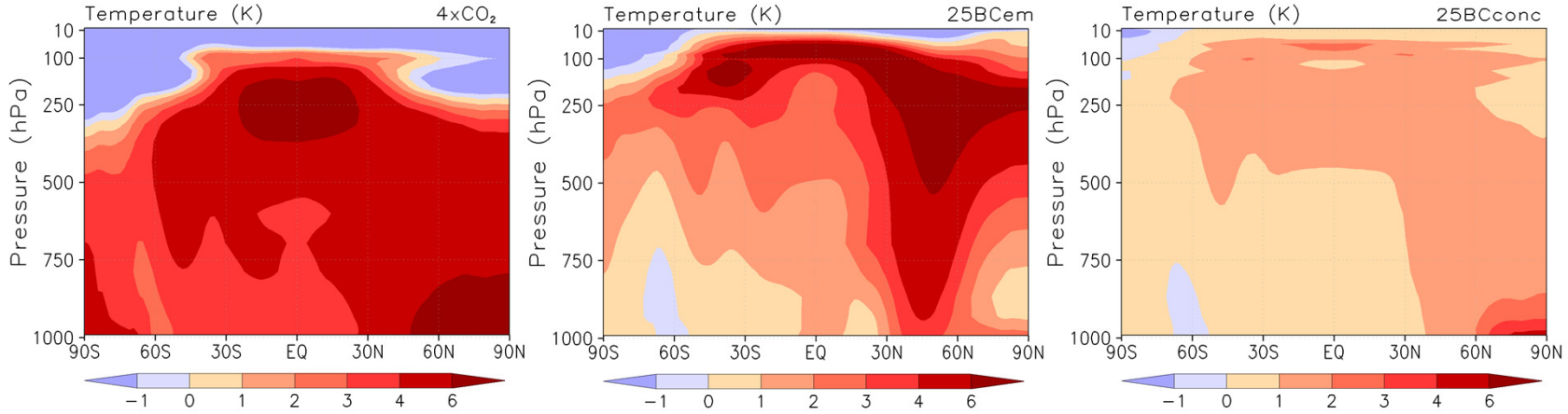


Temperature response



ΔT_s

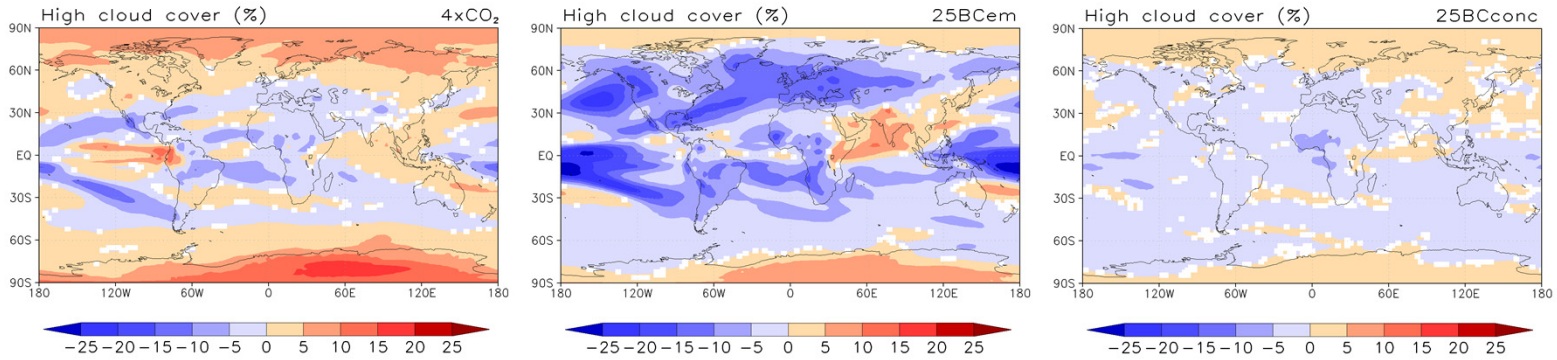
$4xCO_2$ **$25xBC_{emis}$** **$25xBC_{conc}$**



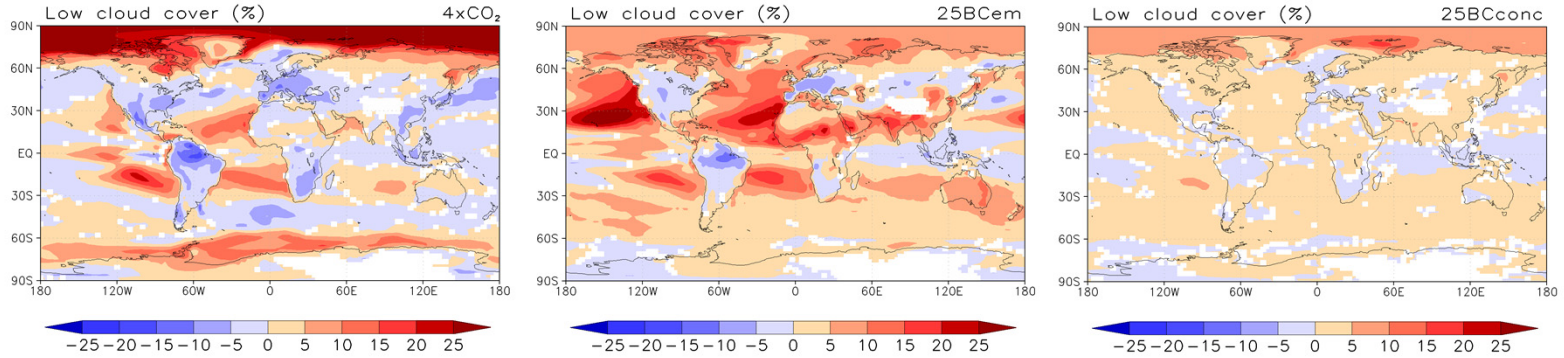
ΔT zonal

Cloud and precip response

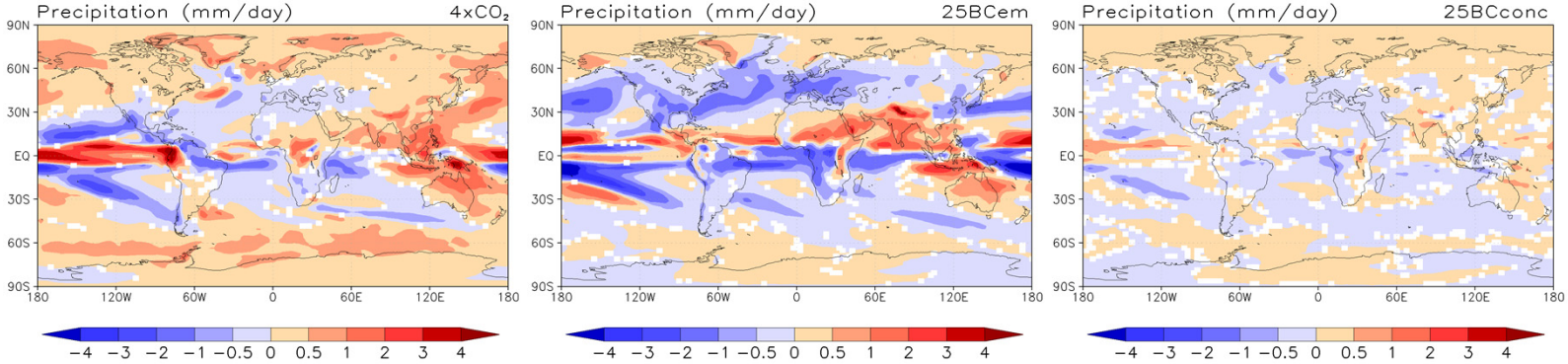
$4xCO_2$ **$25xBC_{emis}$** **$25xBC_{conc}$**



ΔCL_{high} **%**



ΔCL_{low} **%**



ΔP **mm/d**

Climate Sensitivity and feedbacks

The feedback can be divided into

$$\lambda = \lambda_{Pl} + \lambda_{LR} + \lambda_{Alb} + \lambda_{WV} + \lambda_{Cloud}$$

Pl:	Planck Feedback: The direct temperature response;	x=T
LR:	Lapse rate feedback;	x=dT/dz
Alb:	Albedo feedback;	x=a
WV:	Water vapor feedback;	x=q
Cloud:	Cloud feedback;	x=Cl

Radiative Kernels (Soden et al., 2008; Shell et al, 2008 Held and Shell, 2012; Tomassini et al, 2012; Vial et al., 2013)

$$\lambda_x = -\frac{\delta_x \overline{R}}{\delta X}\frac{\delta X}{\delta T_s}$$

From offline radiation code
Soden et al., 2008

From NorESM

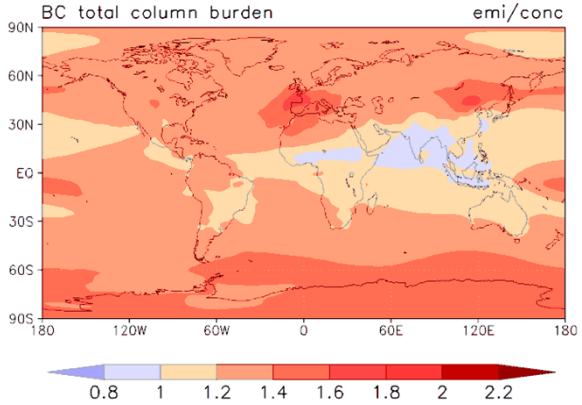
Climate Sensitivity and Feedback

(Soden et al., 2008; Shell et al, 2008 Held and Shell, 2012; Tomassini et al, 2012; Vial et al., 2013)

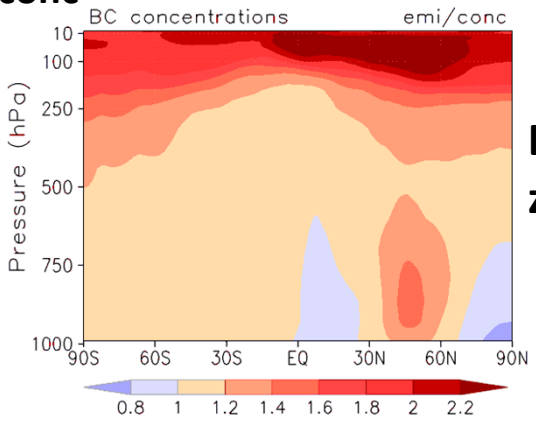
λ_x ($Wm^{-2}K^{-1}$) *All sky*		$4xCO_2$	$25xBC_{emis}$	$25xBC_{conc}$
Planck	**net**	**-3.1**	**-5.6**	**-2.3**
Lapse Rate	**net**	**-0.5**	**-3.0**	**0.3**
Albedo	**net**	**0.3**	**0.7**	**0.5**
Water Vapor	**LW**	**1.2**	**2.6**	**0.8**
	SW	**0.3**	**0.4**	**0.1**
	net	**1.5**	**3.0**	**0.9**
Adj.Cloud RF	**LW**	**0.3**	**-1.9**	**-1.1**
	SW	**0.3**	**1.3**	**0.9**
	net	**0.6**	**-0.6**	**-0.2**
Net Feedback		***-1.2***	***-5.5***	***-0.8***

Why emission-driven?

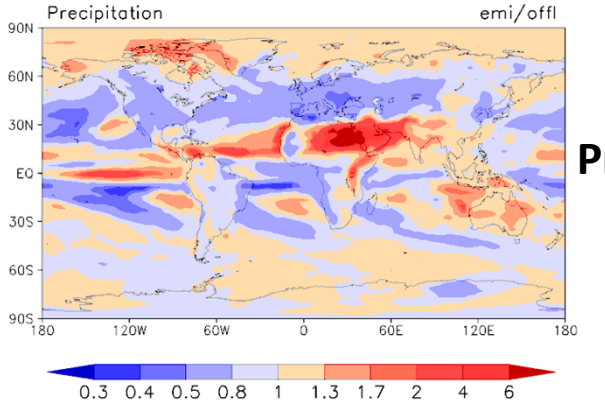
$25xBC_{emis}/25xBC_{conc}$



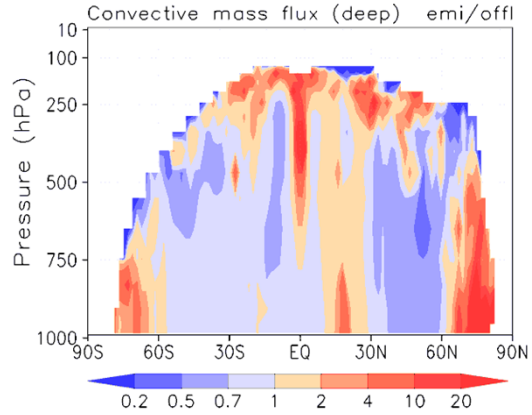
BC burden



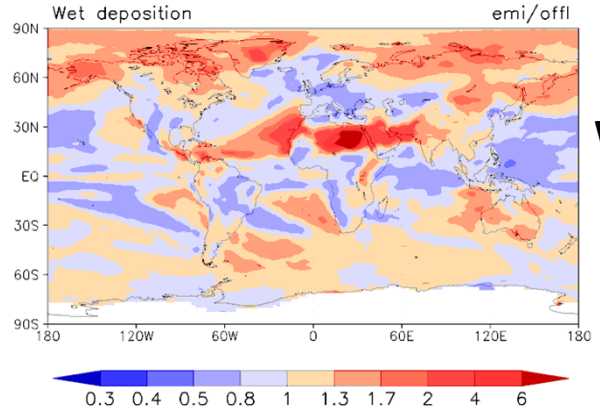
BC conc. zonal



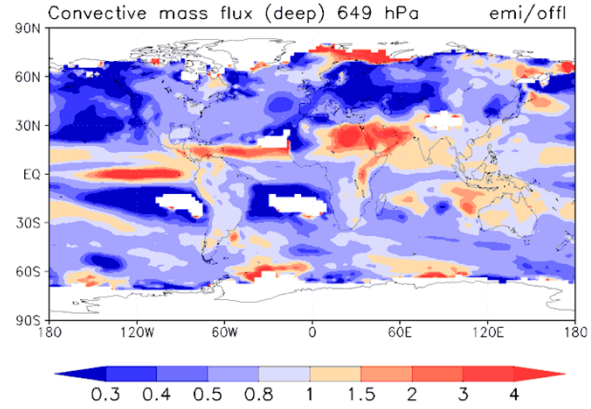
Precip



Convective mass-flux



Wet-dep



Convective mass-flux 649hPa

Conclusions

- **BC-driven climate change differs profundly from CO_2-driven**
- Fast responses dominate for BC
- TOA equilibrium is re-established with little ocean involvement
- Planck-feedback is large
- Lapse-rate and water-vapor feedbacks balance approximately
- Albedo and adj. CRF feedbacks balance approximately

- **Prescribing BC-concentrations is inadequate**
- The BC-induced changes feed positively back on BC-fields
- Northward ITCZ-displacement drives S.-E. Asian BC into the free TS.
- Mid-latitude stabilization, reduced upper-level clouds and precipitation
- Upper-level BC→destabilization of lower stratosphere.

- **Experiments with smaller scaling factors should be made.**


Thank you for the attention
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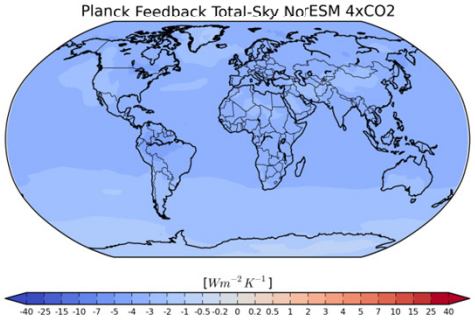
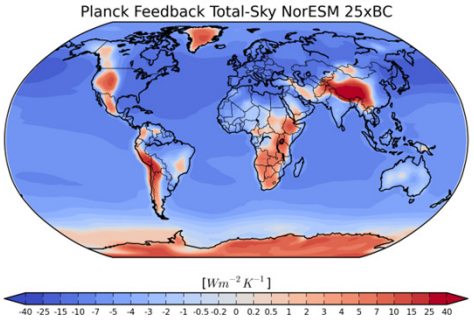
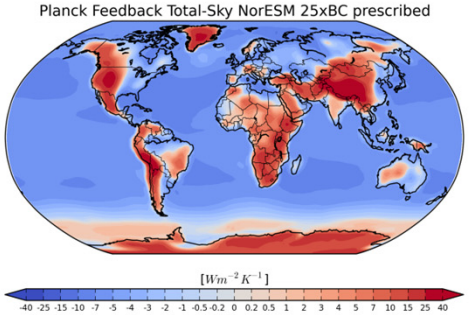
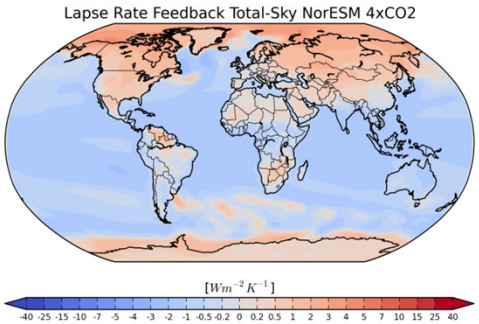
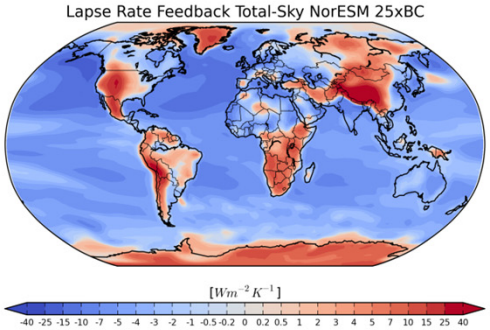
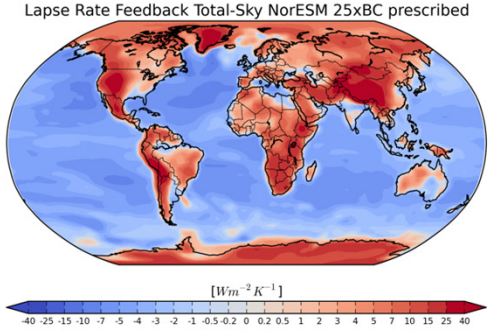
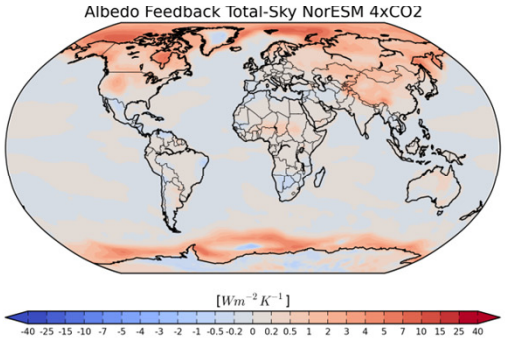
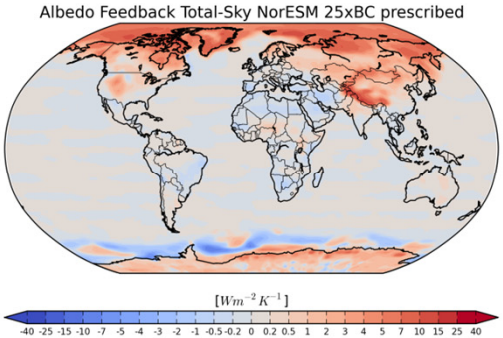
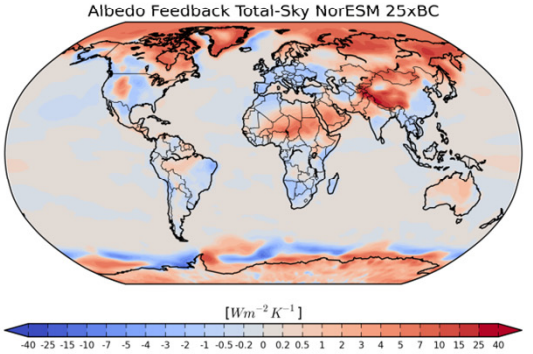
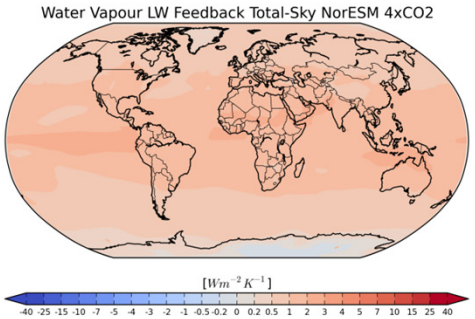
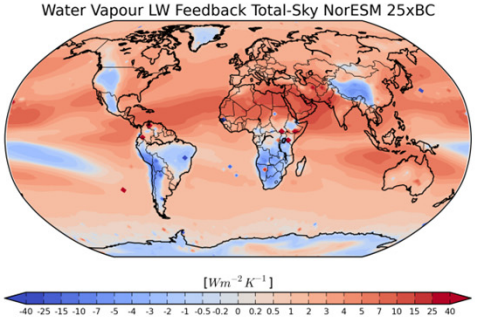
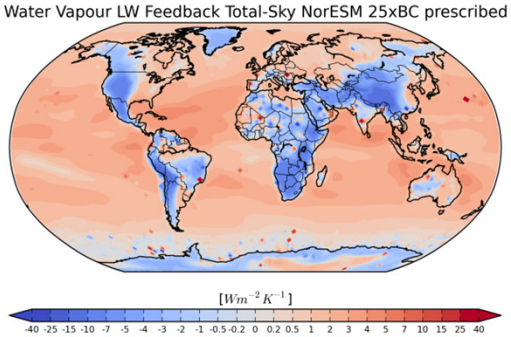
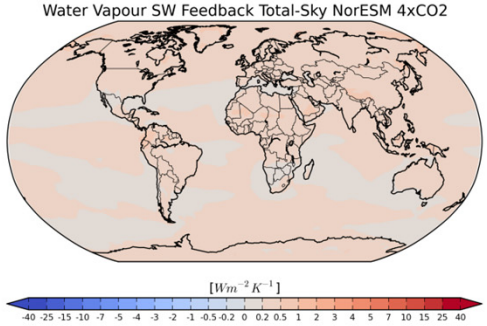
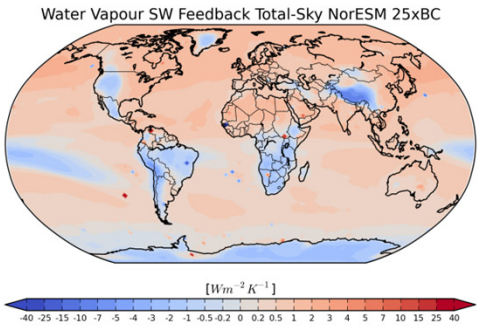
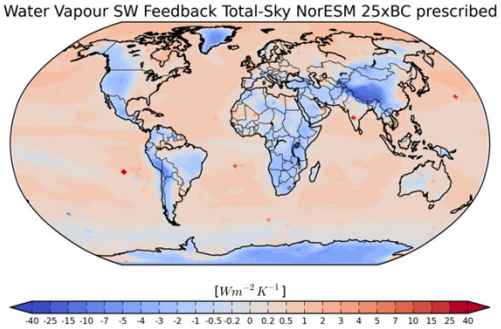
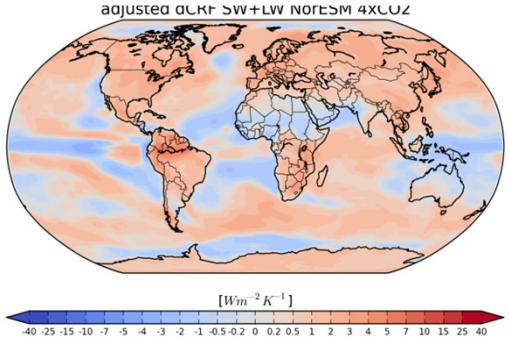
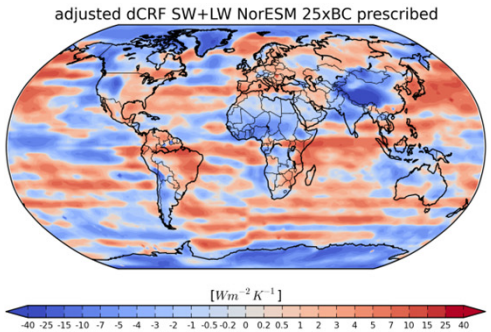
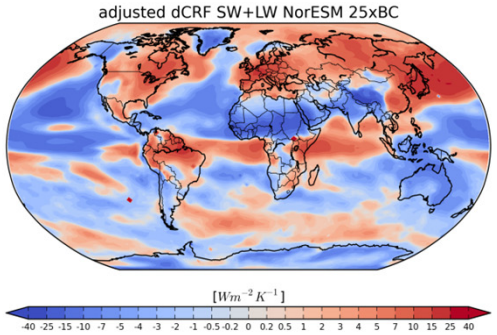
Extra

Climate Sensitivity and feedbacks

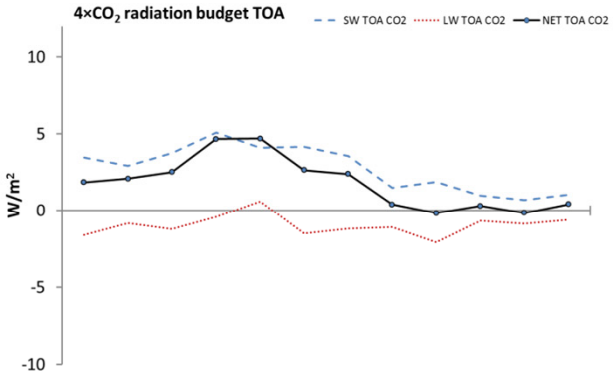
$4xCO_2$	$25xBC_{emis}$	$25xBC_{conc}$	
			λ_{PL}
			λ_{LR}
			λ_{alb}

Climate Sensitivity and feedbacks

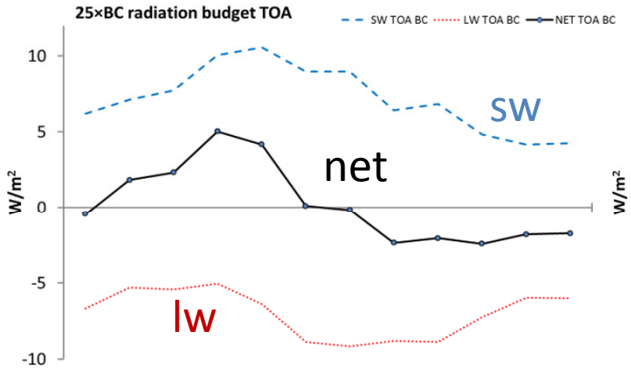
$4xCO_2$	$25xBC_{emis}$	$25xBC_{conc}$	
			λ_{WV} LW
			λ_{WV} SW
			λ_{CRF} adj

Energy Budgets: *30-yr average monthly values*

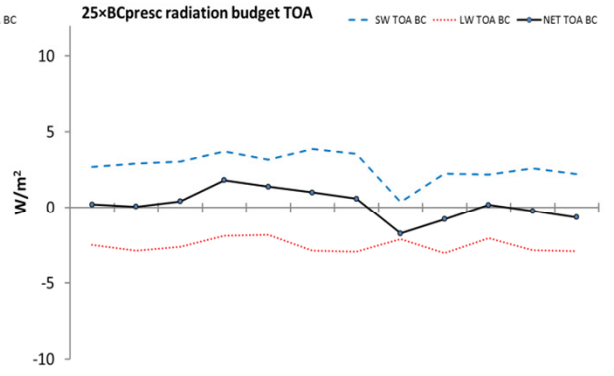
TOA



4xCO$_2$

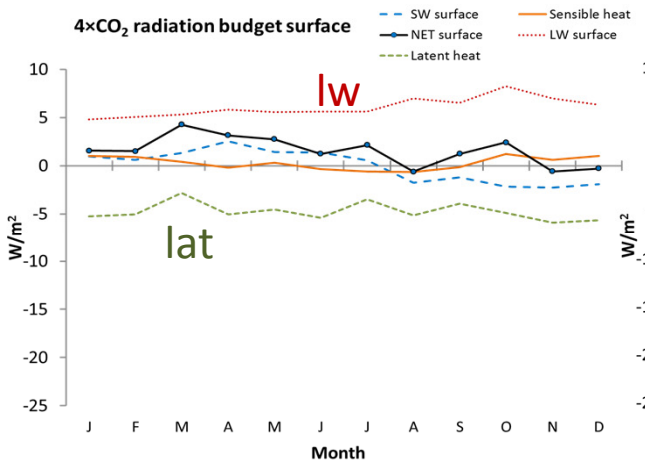


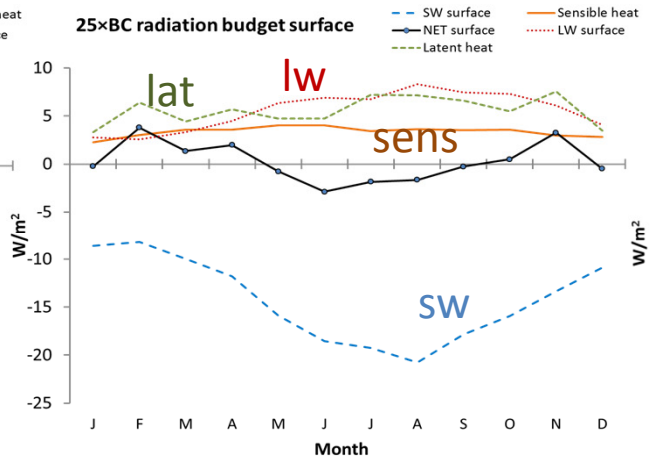
25xBC$_{emis}$

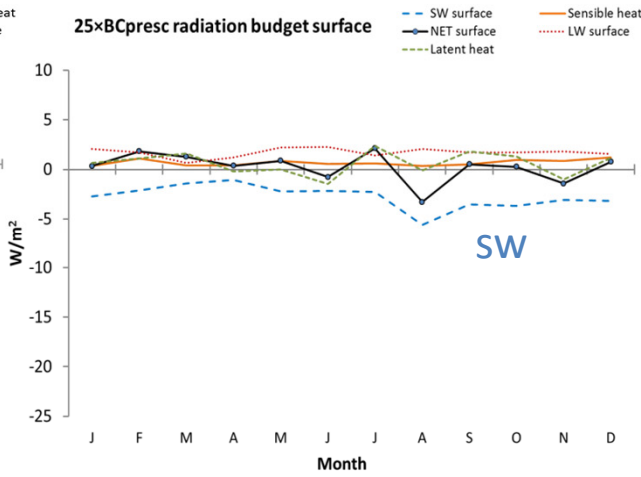


25xBC$_{conc}$

surface







Adjusted Cloud feedbacks

attempts to correct for:

- Non-cloud related changes in atmospheric temperature, humidity, and surface albedos +
- Differences in forcing changes between the clear and all sky forcing.

$$\lambda_{cl} = \left[\frac{dCRF}{dT_{as}}\right] + \left[(\lambda_{T_{clr}} - \lambda_{T_{tt}}) + (\lambda_{WV_{clr}} - \lambda_{WV_{tt}}) + (\lambda_{\alpha_{clr}} - \lambda_{\alpha_{tt}})\right] + \left[\frac{G_{clr} - G_{tt}}{dT_{as}}\right]$$