The dependence of Aerosol-Cloud Indirect Effects on the representation of the autoconversion: Formulation and sensitivity experiments in CESM

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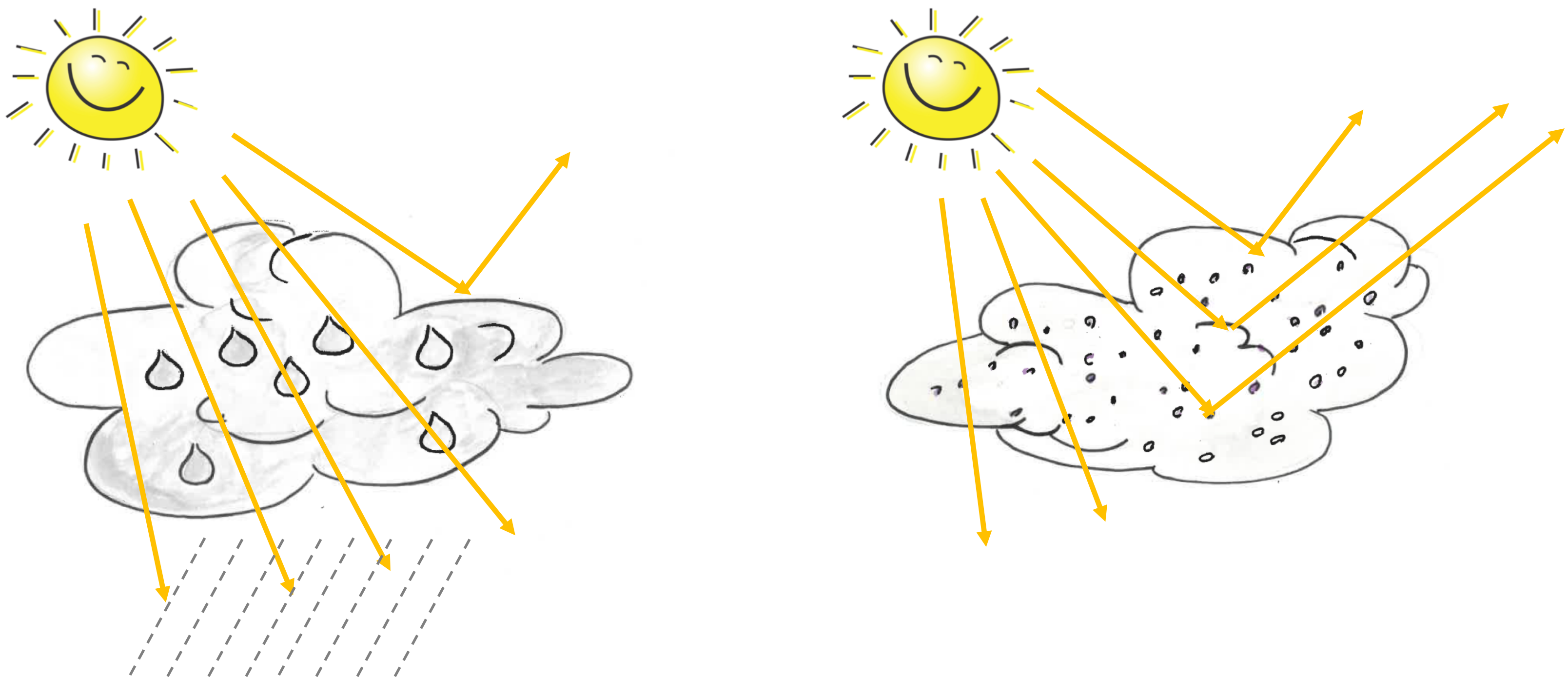
Aerosol Effects on Clouds

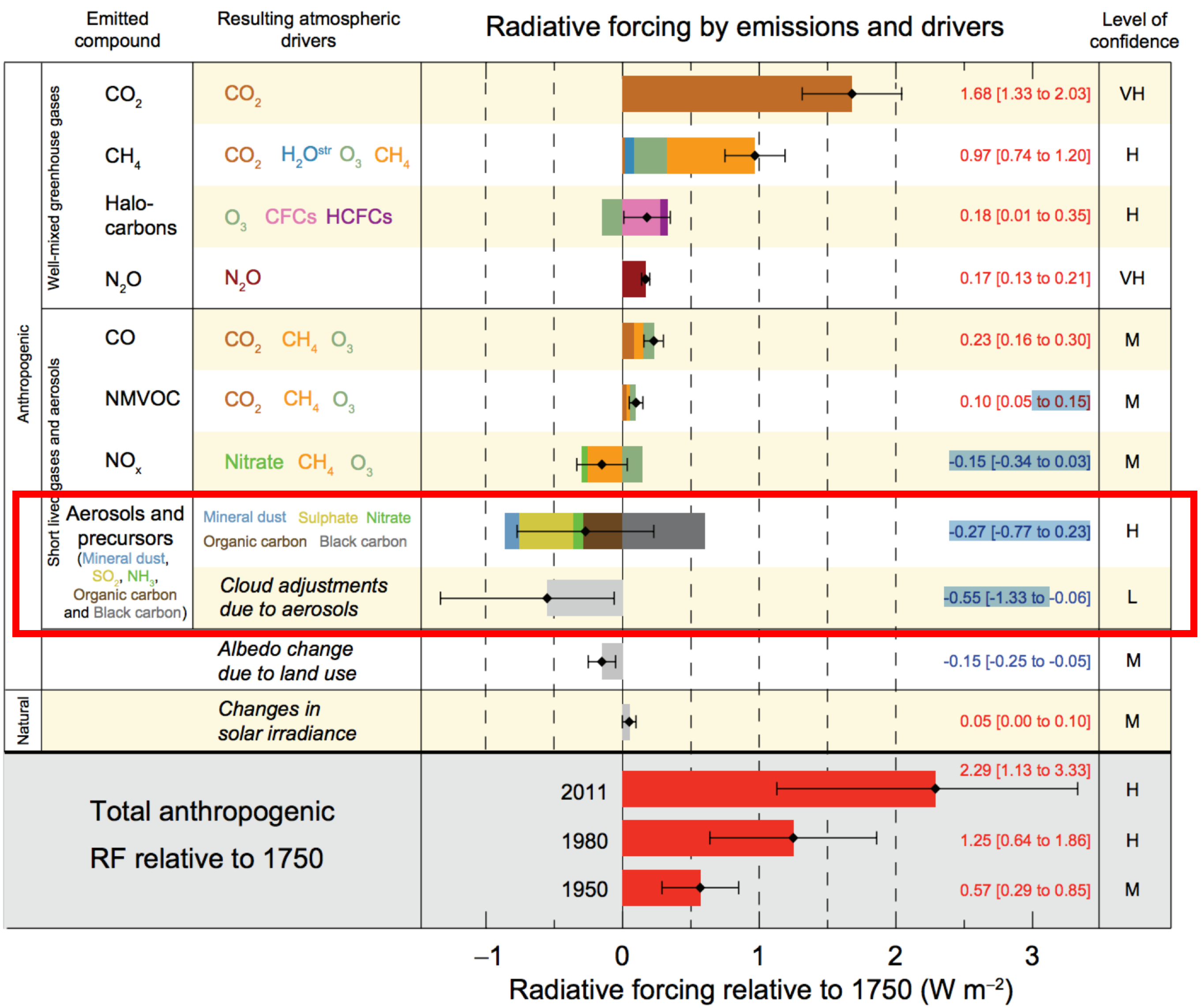
Pristine air (few CCN) | **Polluted air (many CCN)**



Aerosol – Cloud – Interactions (ACI)

Smaller drops => brighter clouds (S. Twomey 1977)
=> delay in precipitation (B. Albrecht, 1989)

Climate Forcing



Greenhouse gases
3.0 ± 0.8 Wm^{-2}

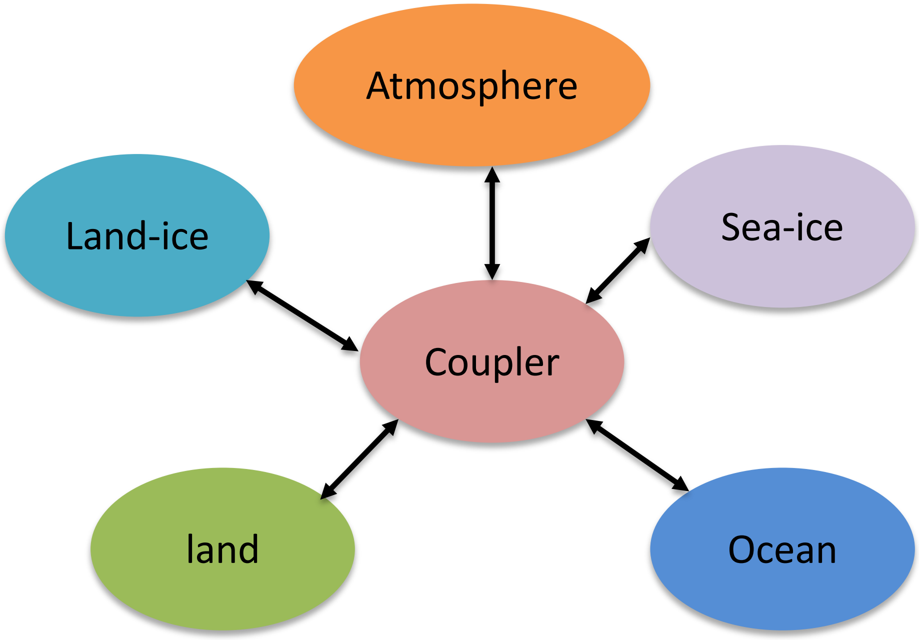
Aerosols
-0.8 ± 1.2 Wm^{-2}

IPCC, 2013, SPM.5

Community Earth System Model (CESM)

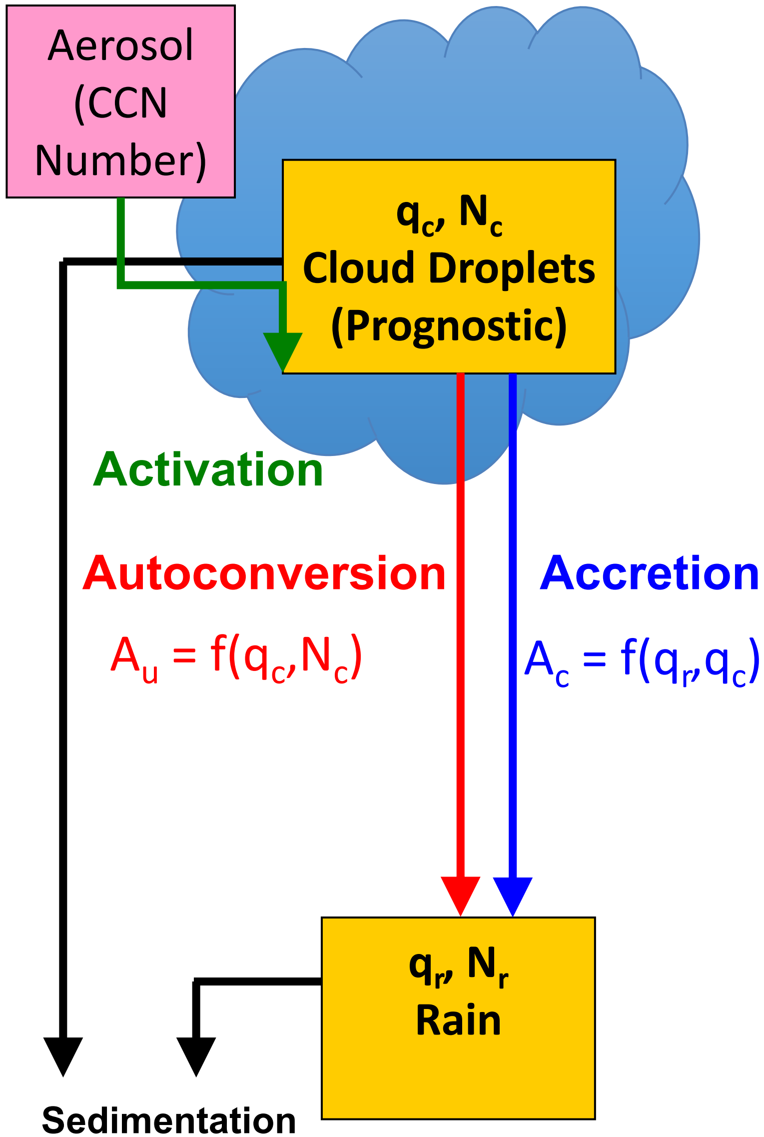
- **CESM is a fully-coupled, global climate model that provides state-of-the-art simulations of the Earth's climate (developed at NCAR)**

- **explicitly simulates Aerosol-Cloud Interactions making it possible to simulate aerosol indirect effects**



http://www.cesm.ucar.edu/

Aerosol Cloud Interactions in CESM2



1. **Activation (CCN) = f(RH,w)**
   W at cloud scale is critical

2. **Autoconversion (loss process) is a function of N_c (=ACI)**

3. **Accretion depends on q_r**

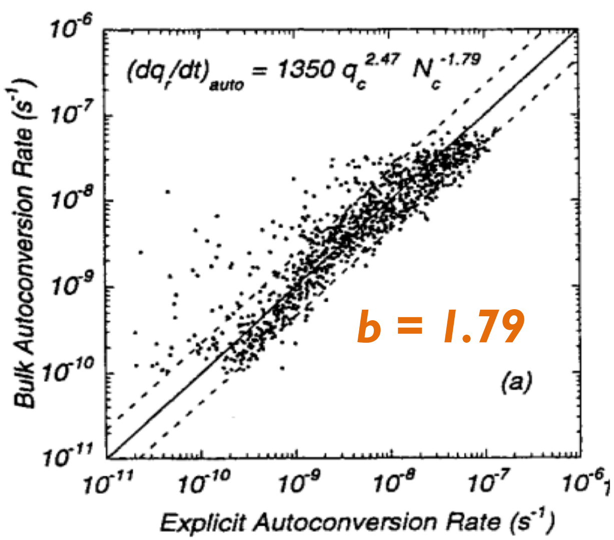
Autoconversion parameterization

Khairoutdinov and Kogan scheme (KK2000)

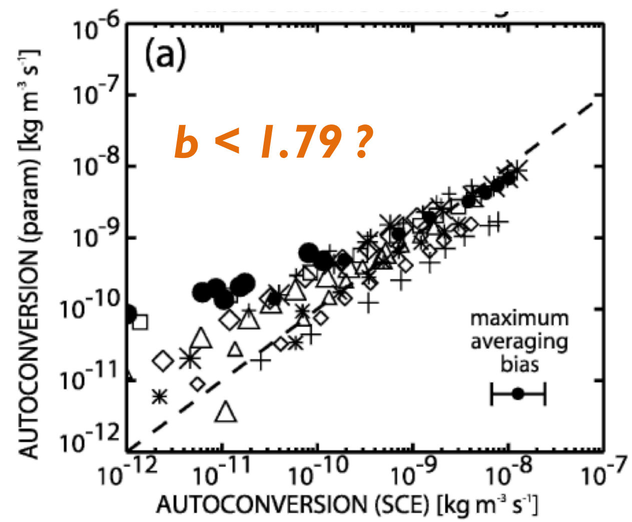
$$A = k\, q_c^{a}\; N_c^{-b}$$

A = autoconversion rate
q_c = cloud liquid (kg/kg)
N_c = droplet number (#/kg)

KK2000

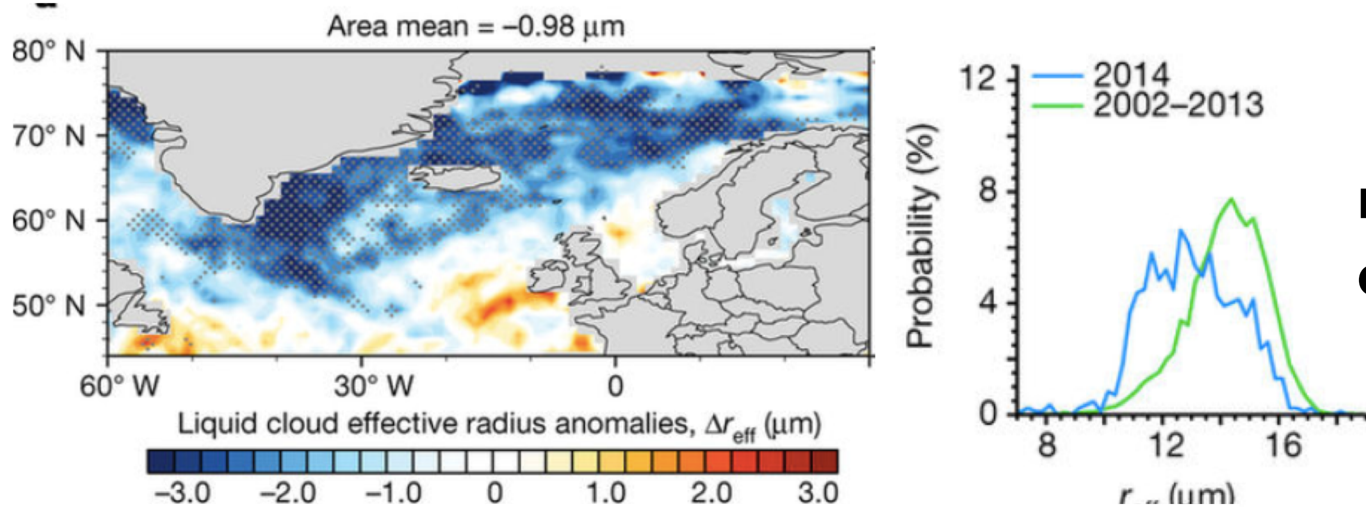


Wood 2005



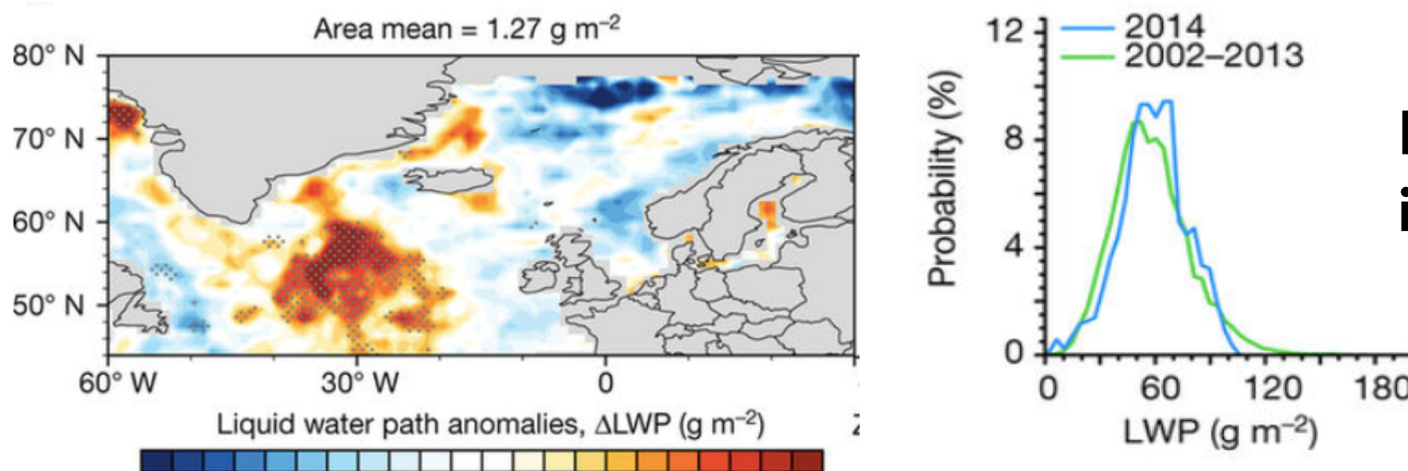
Obs: Holuhraun eruption, Iceland (2014-2015)

Change in Cloud Top Particle Size (MODIS)



reduced cloud droplets size

Change in Liquid Water Path (MODIS)

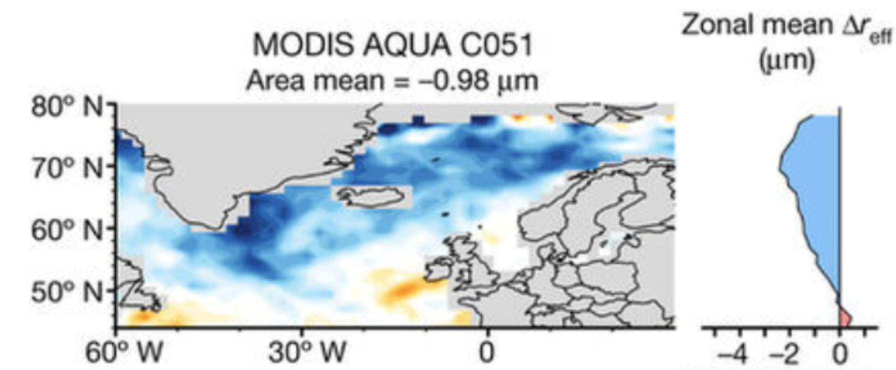


No change in LWP

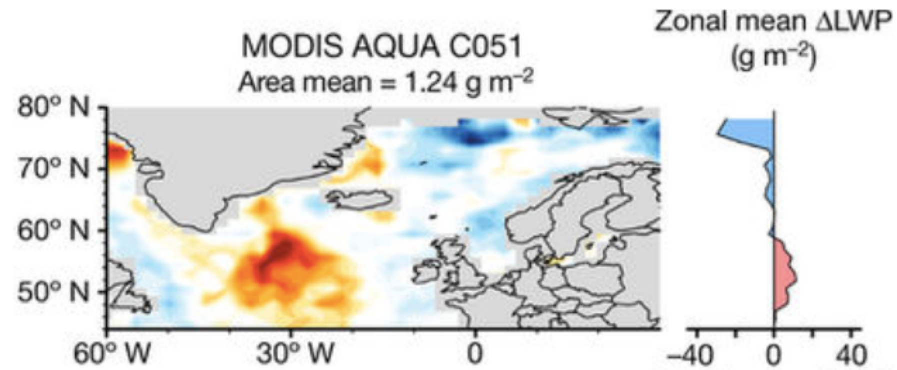
Malavelle et al 2017, Nature

Holuhraun eruption: Model versus obs anomalies

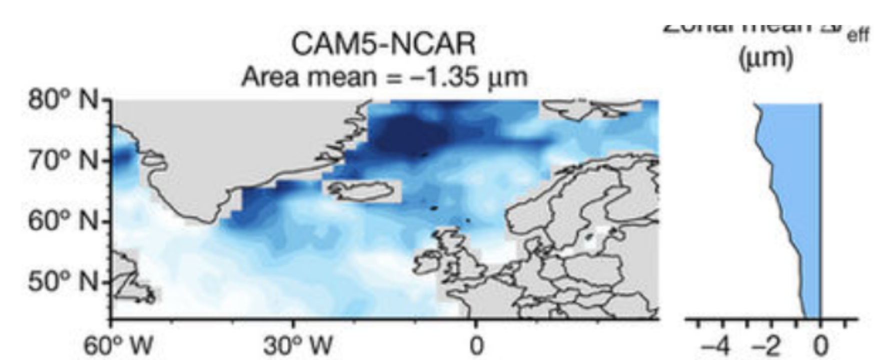
Cloud Top Particle Size (MODIS)



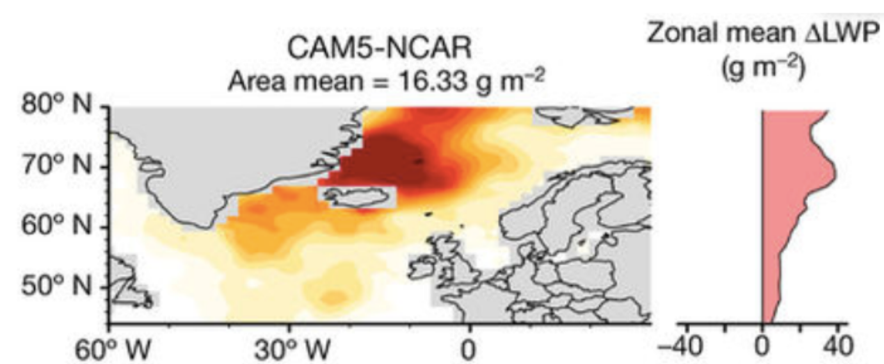
Liquid Water Path (MODIS)

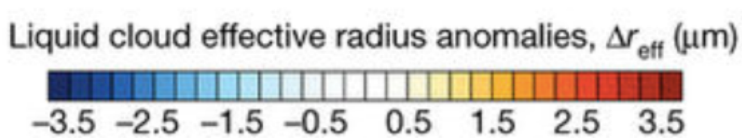


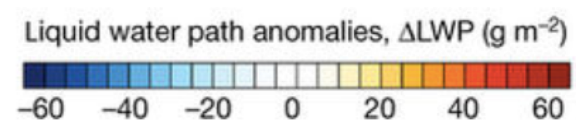
Cloud Top Particle Size (CESM1)



Liquid Water Path (CESM1)







Malavelle et al 2017, Nature

CESM1 overestimates the change in LWP

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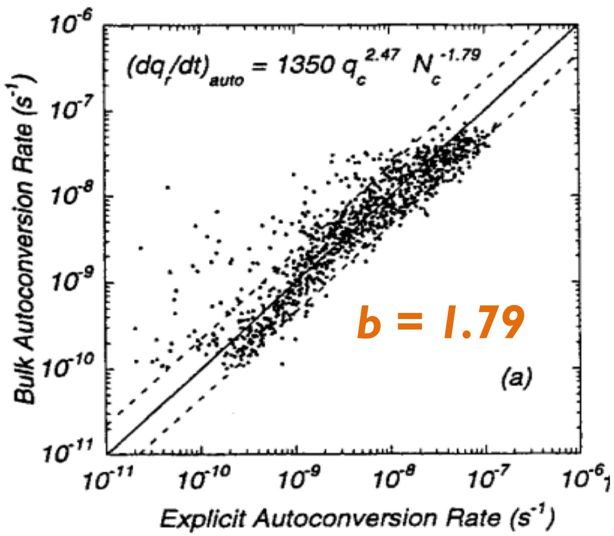
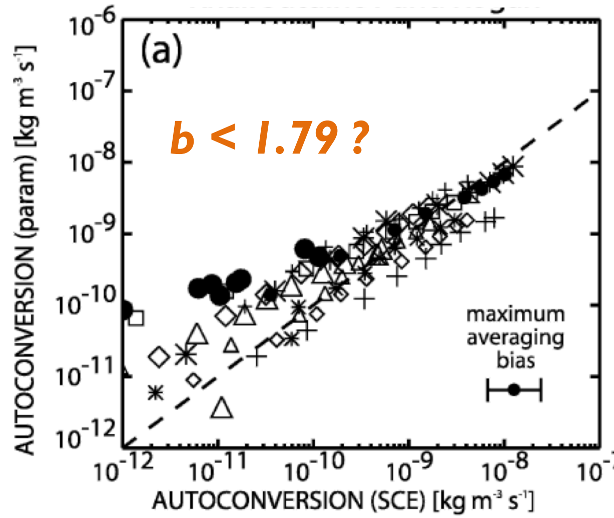
KK2000



Wood 2005



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Sensitivity experiments: Varying exponent b

b	
1.79	KK2000
1.1	Wood, personal communication
0.5	Extreme value

+ adjust k to produce the same autoconversion rate

Sensitivity Experiments

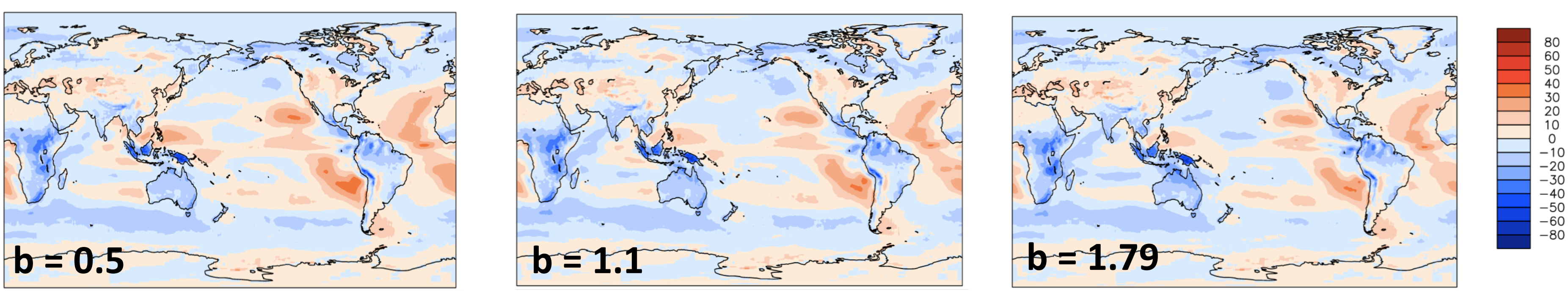
$$A = k\, q_c^{a}\ N_c^{-b}$$

5-year runs with prescribed climatological present-day SSTs

Similar climate after retuning (k and Dcs)

exp b	k /1350	SWCF W/m2	LWCF W/m2	LWP	Dcs microns
0.5	0.002	-47.4	24.1	68.1	540
1.1	0.01	-48.4	24.8	68.4	540
1.79	0.06	-48.7	24.3	66.4	300

SWCF bias compared to CERES-EBAF: Similar bias

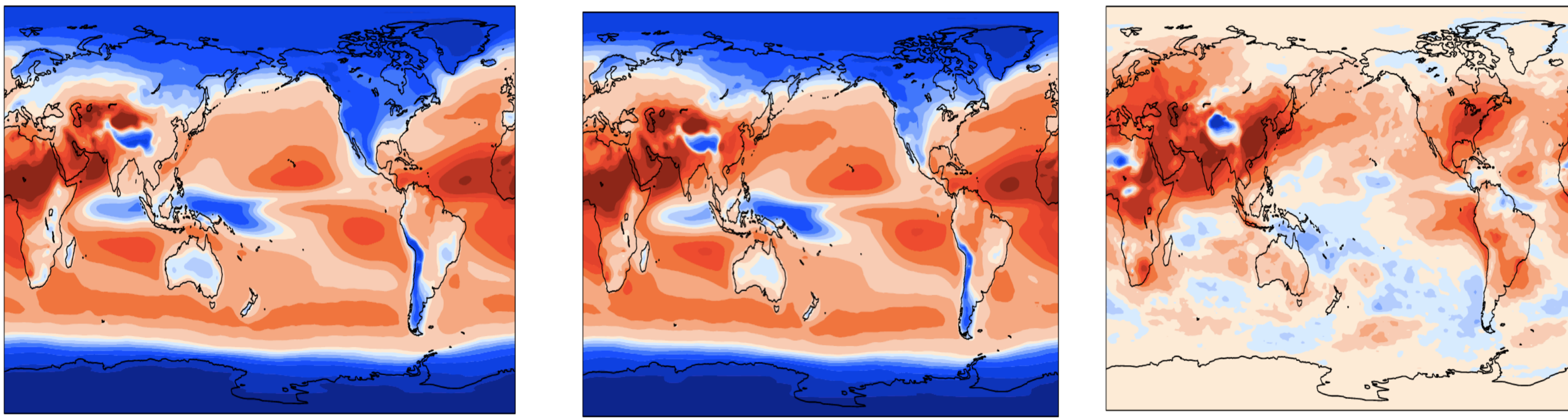


Estimation of the aerosol indirect effect

Compare two simulations →
- **present day aerosol (2000)**
- **pre-industrial aerosol (1850)**

Aerosol Optical Depth

1850 | **2000** | **2000 - 1850**



Look difference between 2 runs:

ΔRESTOM => Aerosol total effect

ΔSWCF => Cloud albedo effect (1st indirect effect)

ΔLWP => Cloud lifetime effect (2nd indirect effect)

Estimation of the aerosol indirect effect

Compare two simulations → **present day aerosol (2000)**
→ **pre-industrial aerosol (1850)**

Aerosol Optical Depth

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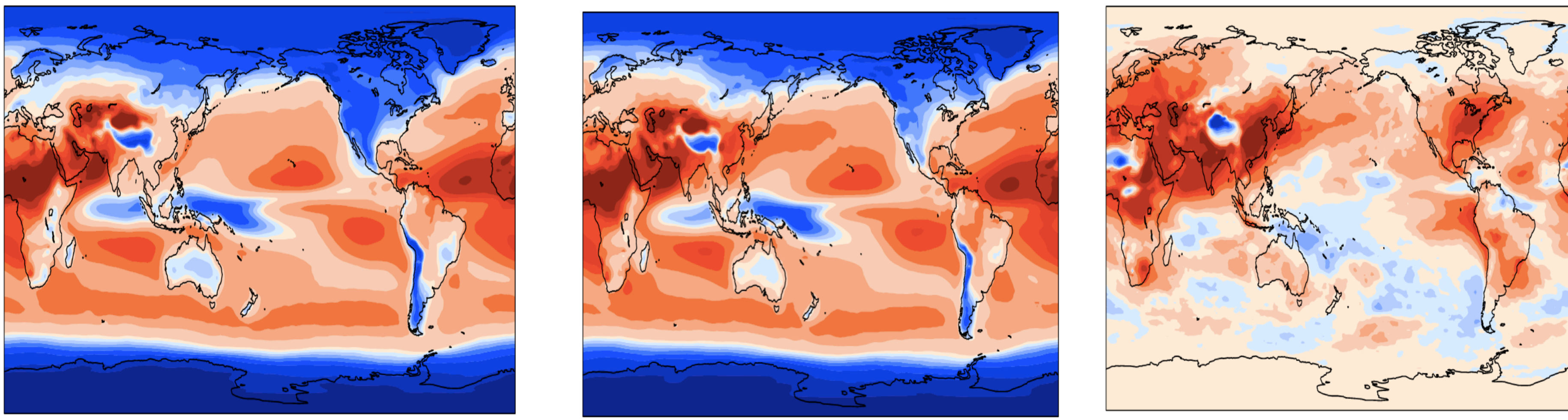
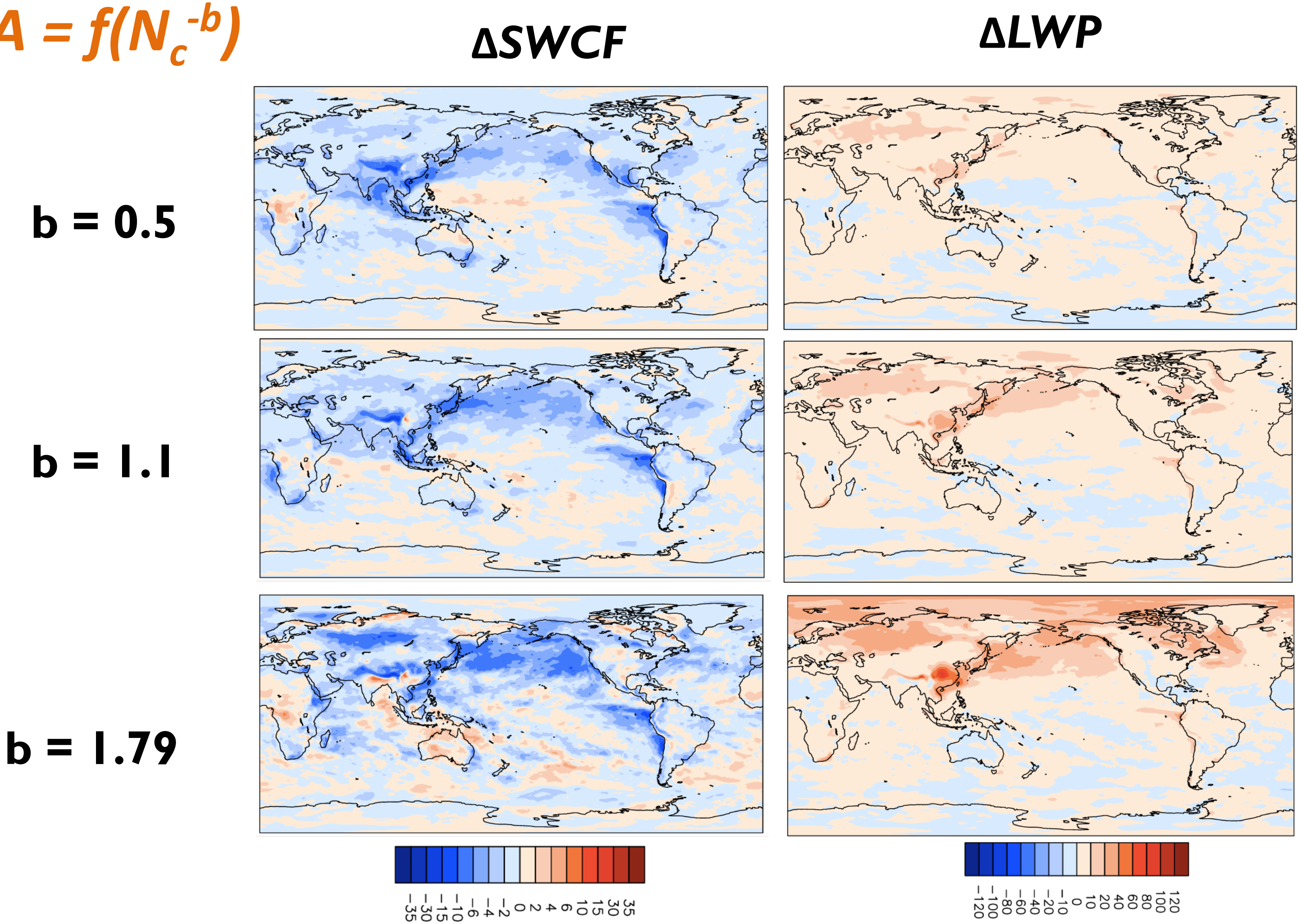


	b = 1.79	b = 1.1	b = 0.5	
ΔRESTOM (W/m2)	-1.56	-1.27	-1.18	Total effect
ΔSWCF (W/m2)	-1.29	-1.17	-1.11	1st indirect effect
ΔLWP (%)	7.3%	4.72%	2.35%	2nd indirect effect

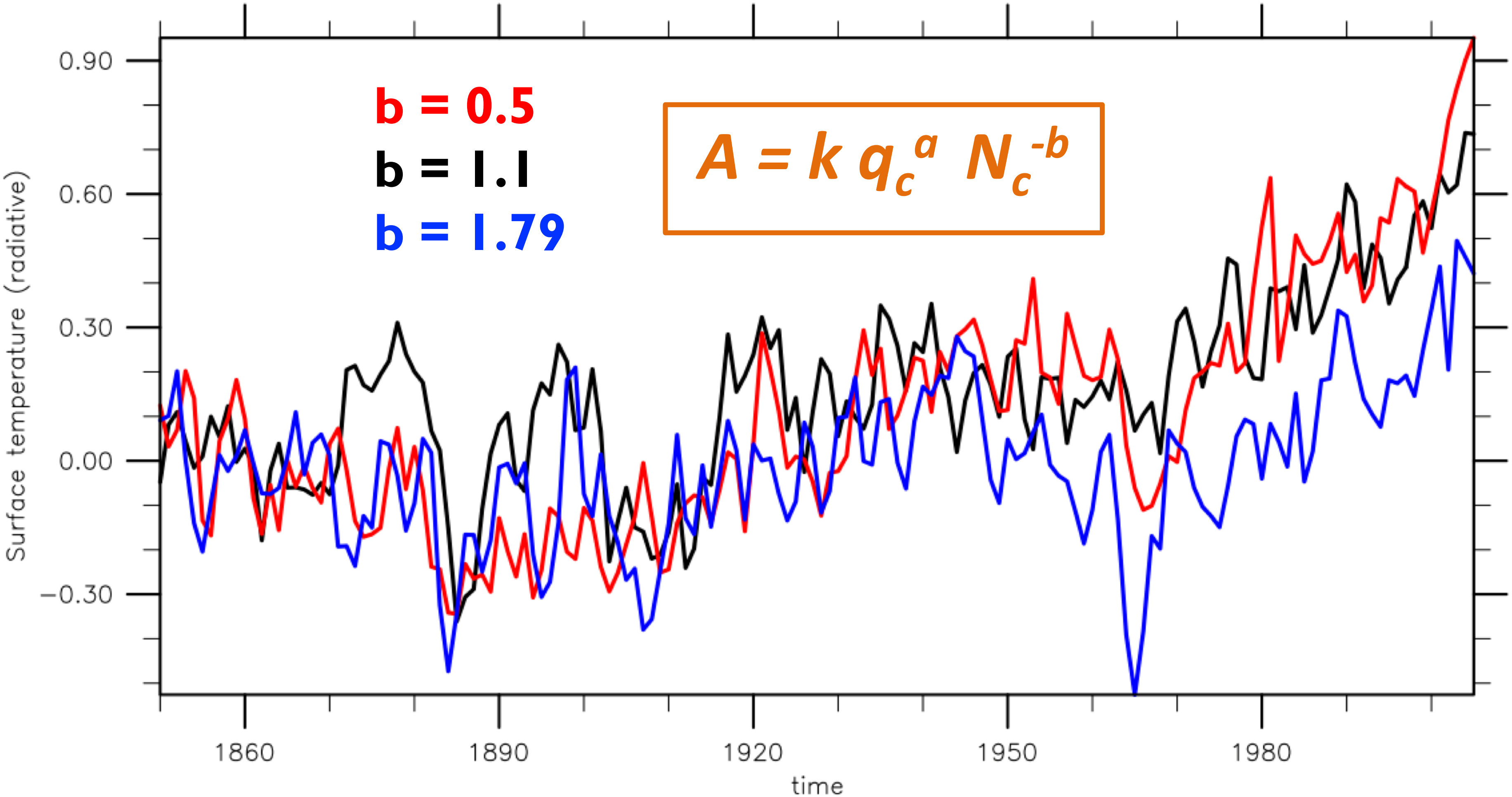
Difference in SWCF and LWP in 2000-1850 aerosol

$A = f(N_c^{-b})$



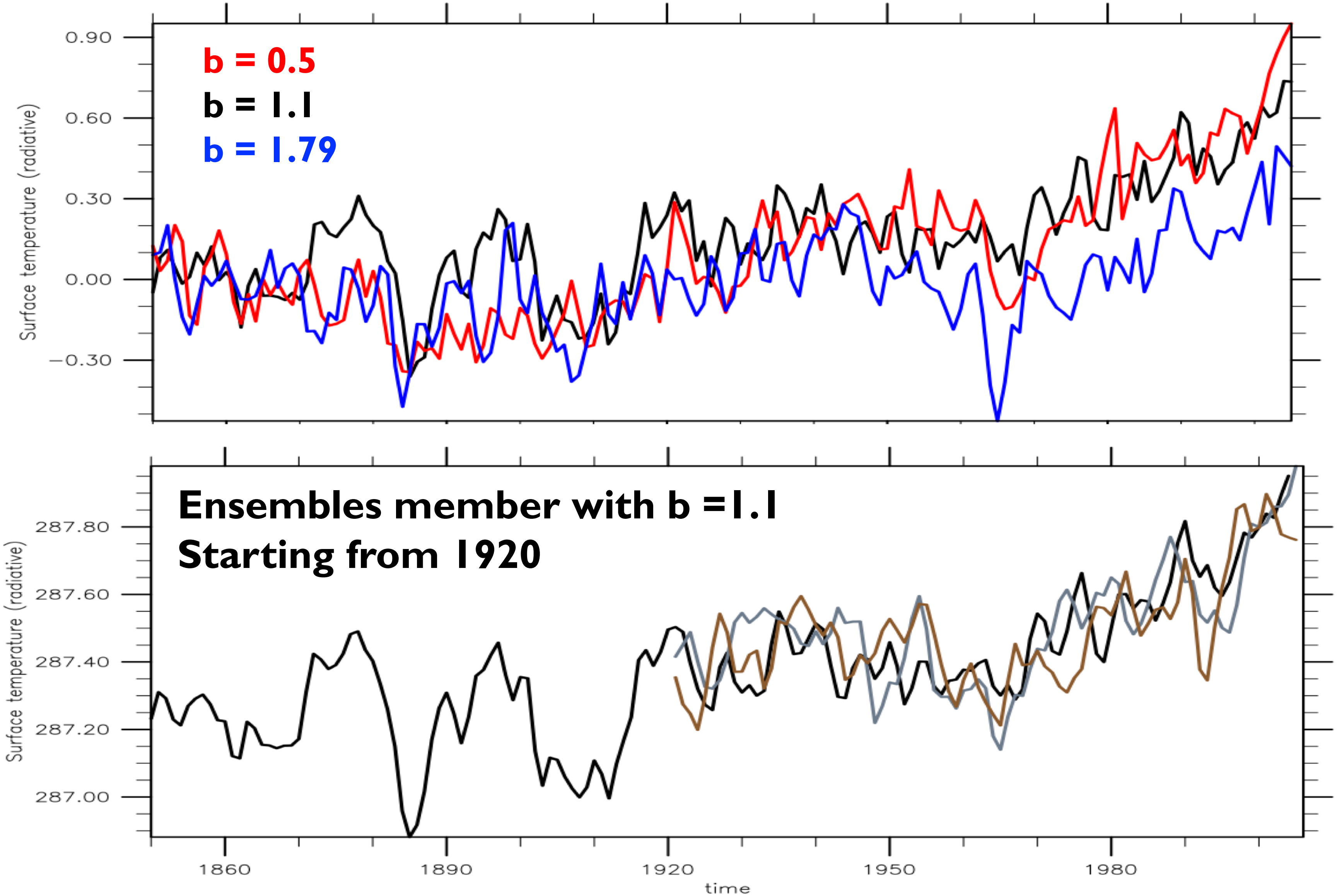
Impact on 20th century surface temperature

Has a large impact on the period 1940-1960



20th century variability

Impact is not within the variability range



Summary

Malvelle, 2017: the Holuhraun eruption reduced the size of liquid cloud droplets had no discernible effect on other cloud properties like LWP.

Autoconversion KK 2000: $A = k\, q_c^{a}\ N_c^{-b}$

Sensitivity tests with b = 0.5, 1.1, 1.79 impacts indirect effects (change in SWCF and LWP)

Change in b has a direct impact on the period 1940-60