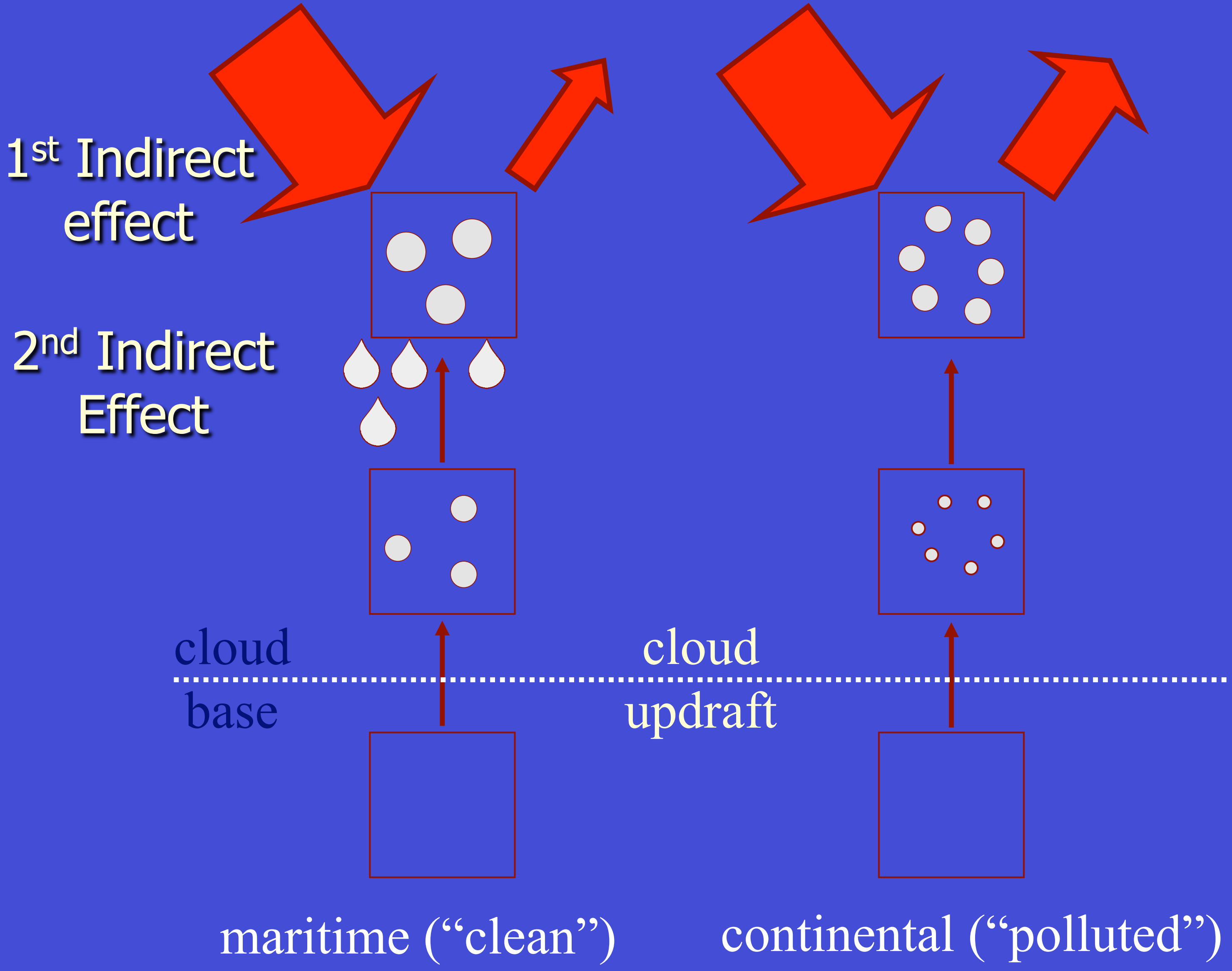
Indirect aerosol effects in idealized simulations of convective-radiative quasi-equilubrium. Double-moment microphysics

Wojciech W. Grabowski and Hugh Morrison

National Center for Atmospheric Research, Boulder, Colorado

Indirect aerosol effects (warm rain only)



1st Indirect effect

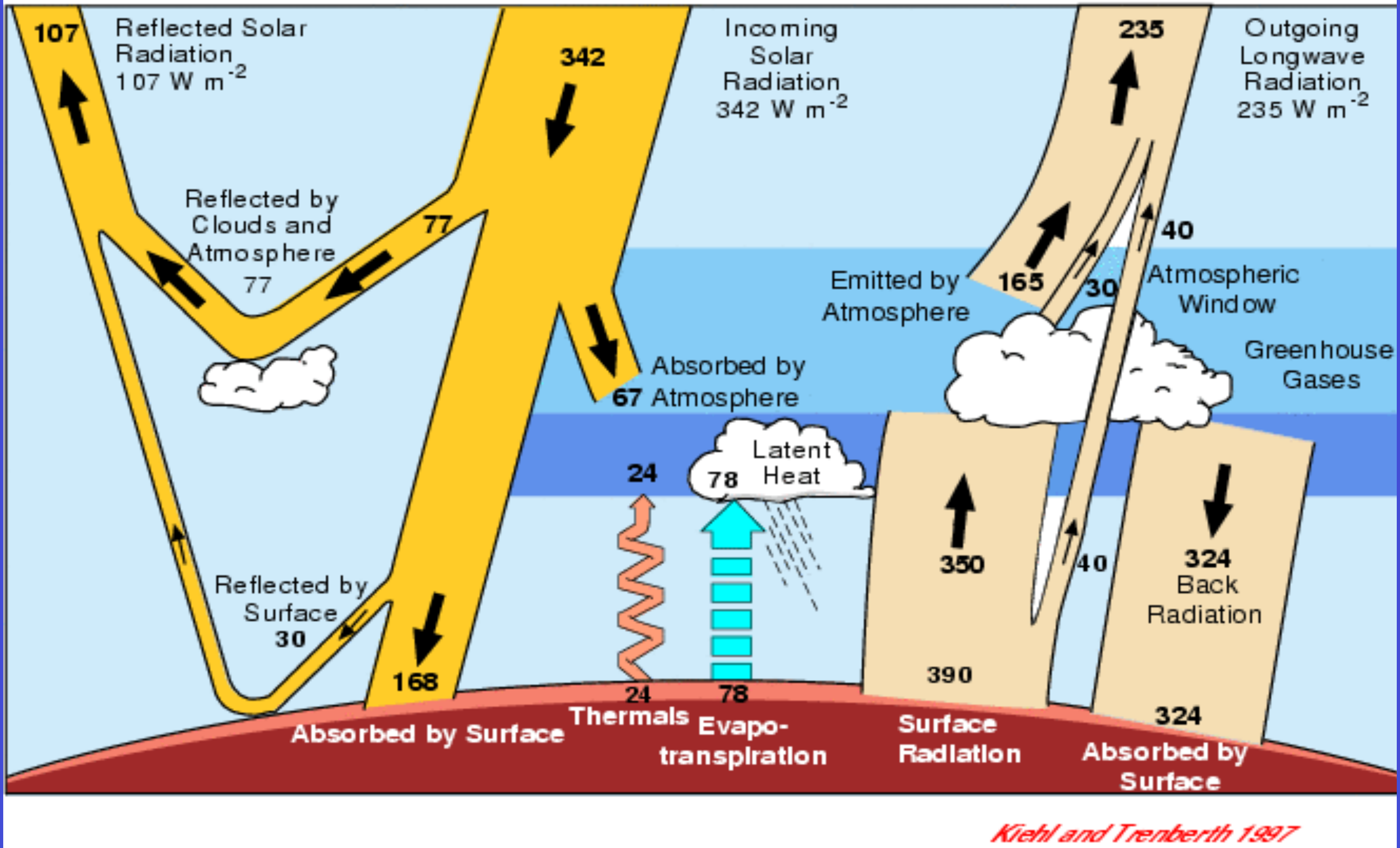
2nd Indirect Effect

cloud base

cloud updraft

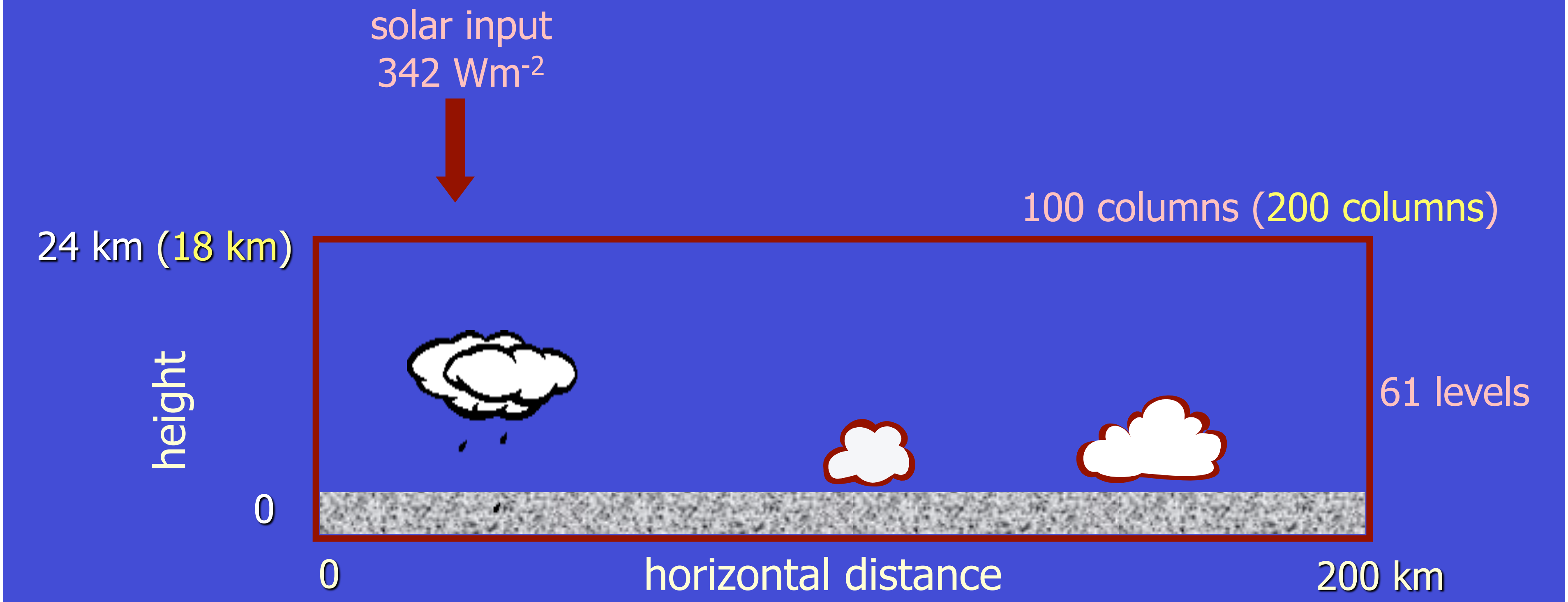
maritime (“clean”)

continental (“polluted”)



The Earth annual and global mean energy budget

Radiative-convective quasi-equilibrium mimicking planetary energy budget using a 2D cloud-resolving model



solar input

342 Wm^{-2}

100 columns (200 columns)

24 km (18 km)

height

61 levels

0

0

horizontal distance

200 km

Surface temperature = 15° C

Surface relative humidity = 85%

Surface albedo = 0.15

Grabowski *J. Climate* 2006

Numerical model:

- Dynamics: 2D super-parameterization model (Grabowski 2001) with simple bulk microphysics (warm-rain plus ice; Grabowski 1998)
- Radiation: NCAR's Community Climate System Model (CCSM) (Kiehl et al 1994) in the Independent Column Approximation (ICA) mode
- 100 columns (Δx=2km) and 61 levels (stretched; 12 levels below 2 km; top at 24 km)

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1^{st} and 2^{nd} indirect effects of water clouds:

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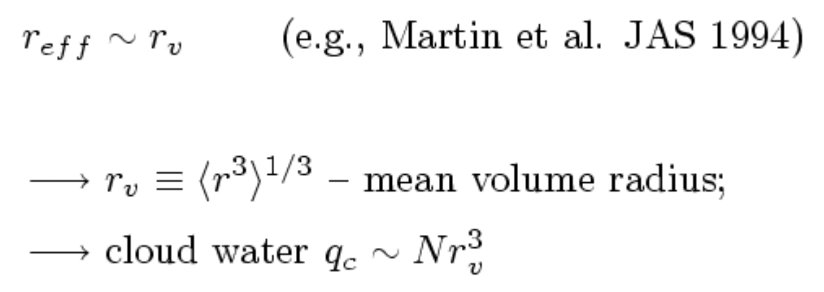
	"pristine"	"polluted"
cloud droplet concentration (cm^{-3})	100	1,000

1^{st} effect: a simple parameterization of the effective radius:



$r_{eff} \sim r_v$ (e.g., Martin et al. JAS 1994)

$\longrightarrow r_v \equiv \langle r^3 \rangle^{1/3}$ – mean volume radius;

$\longrightarrow$ cloud water $q_c \sim N r_v^3$

2^{nd} effect: Berry's parameterization of the conversion from cloud water to rain.

No impact on ice physics was considered.

Effective radius for ice particles…

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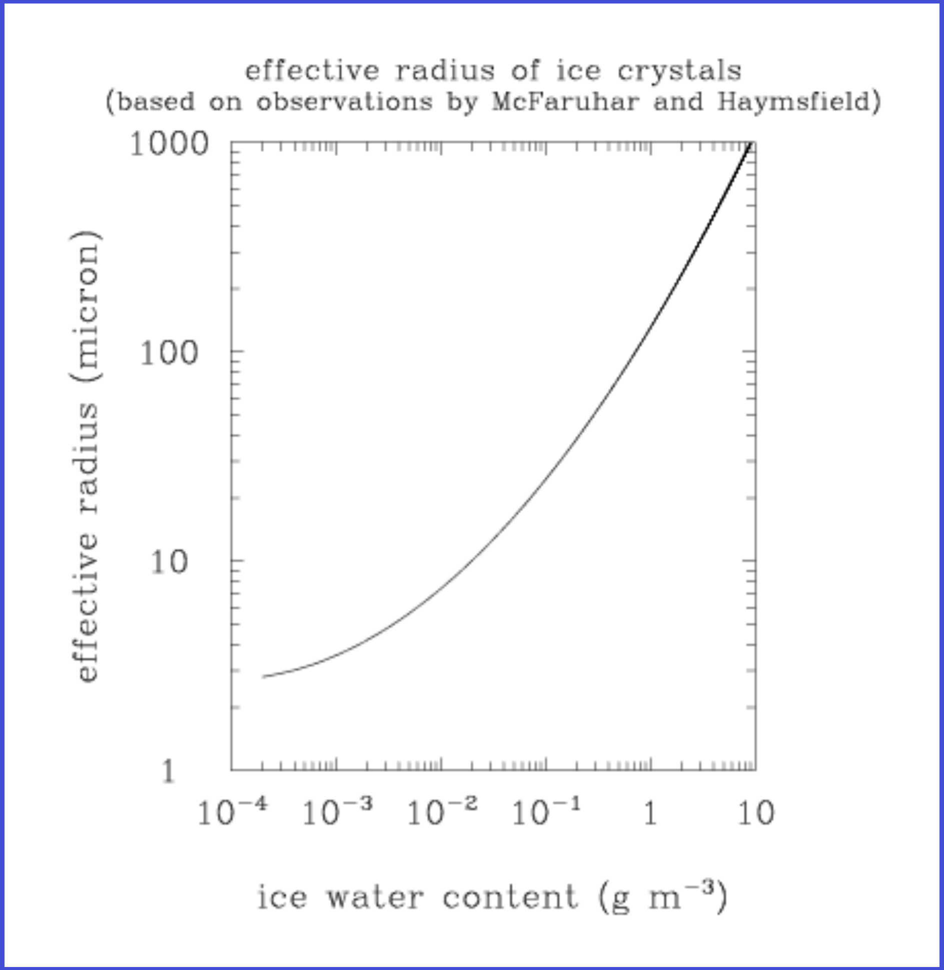

This formula was used in all simulations (i.e., no indirect effect on ice processes).

Simulations with the new double-moment bulk microphysics:

Warm-rain scheme of Morrison and Grabowski (JAS 2007, 2008a) predicts concentrations and mixing ratios of cloud water and rain water; relatively sophisticated CCN activation scheme (with pristine and polluted CCN spectra) and representation of the homogeneity of subgrid-scale mixing.

Ice scheme of Morrison and Grabowski (JAS 2008b) predicts concentrations and two mixing ratios of ice particles to keep track of mass grown by diffusion and by riming; heterogeneous and homogeneous ice nucleation with the same IN characteristics for pristine and polluted conditions.

Better spatial resolution (200 points with 1 km gridlength, 61 levels up to 18 km)

60-day long simulations starting from the sounding at the end of the single-moment simulations of Grabowski (2006).

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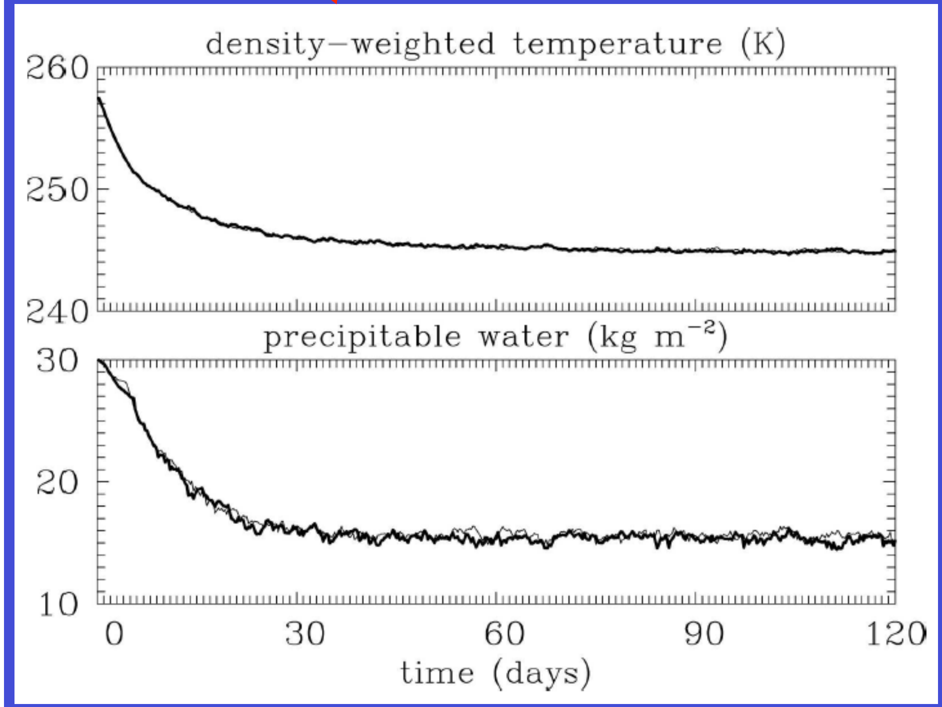
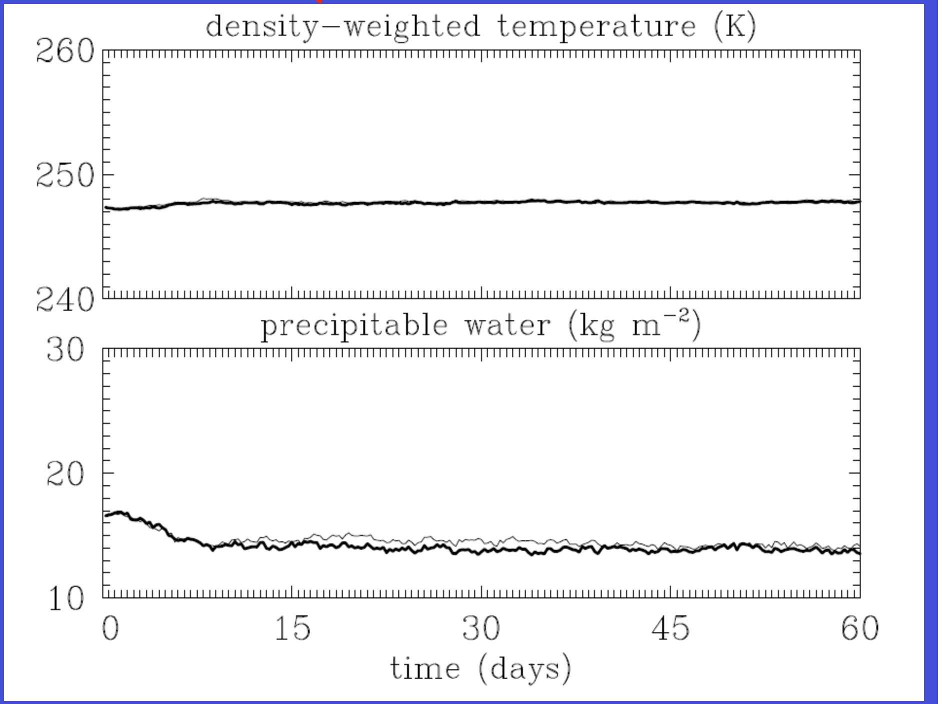


new simulation



Grabowski
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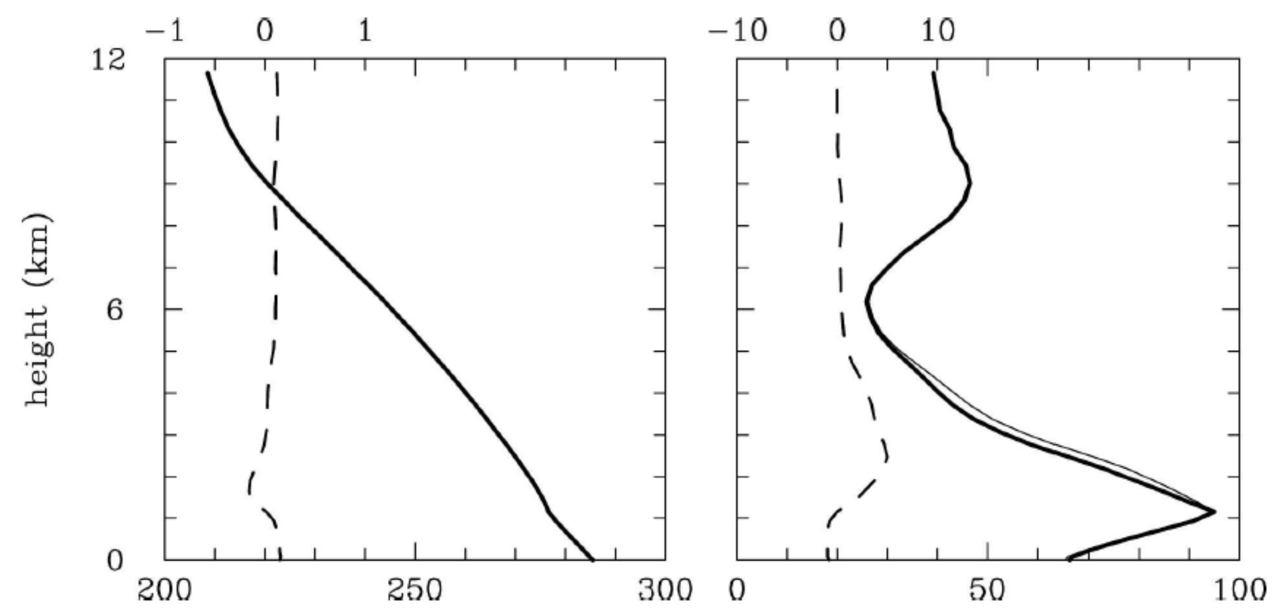
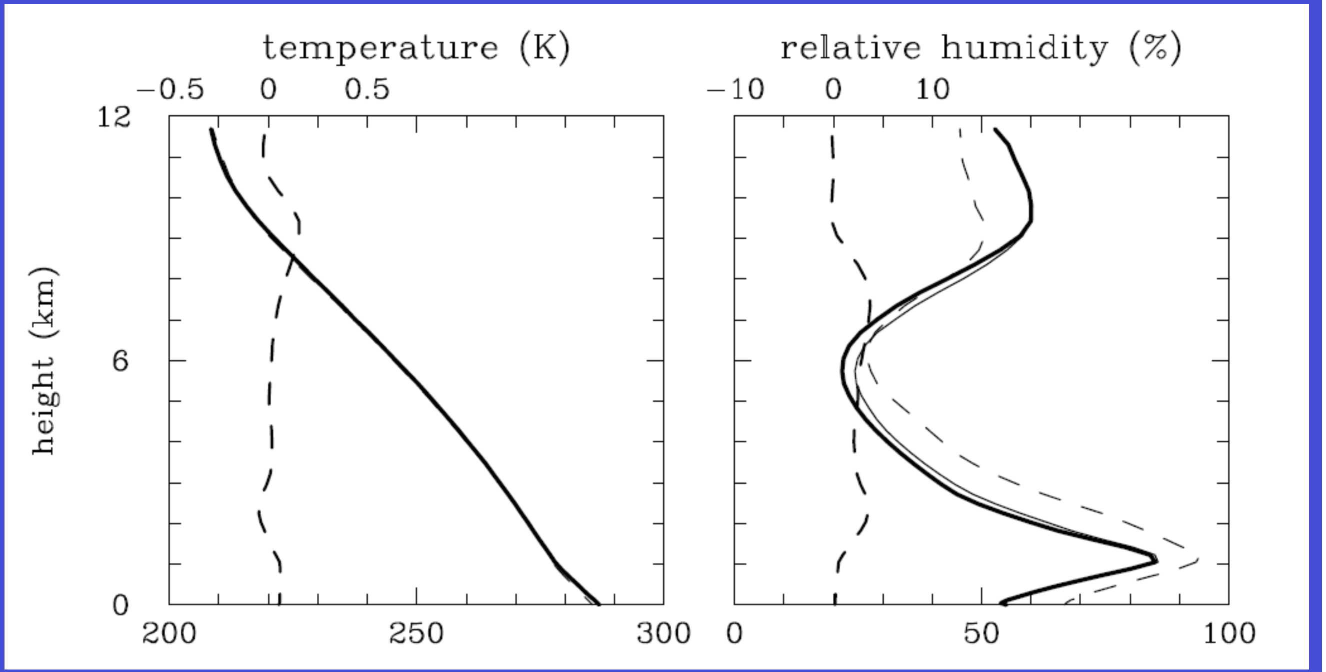


Thin: polluted
Thick: pristine
Dashed: polluted-pristine

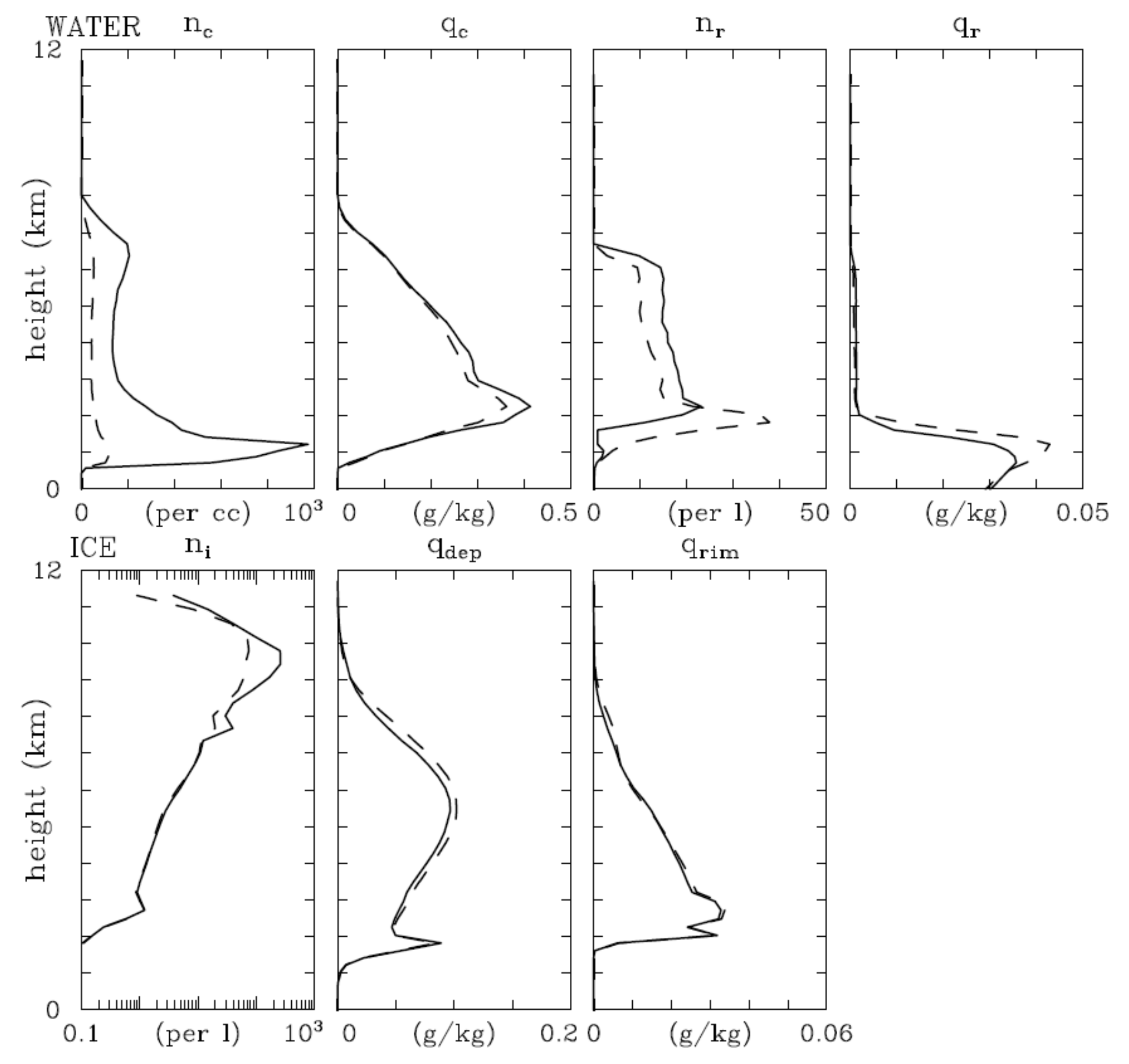
new
simulations



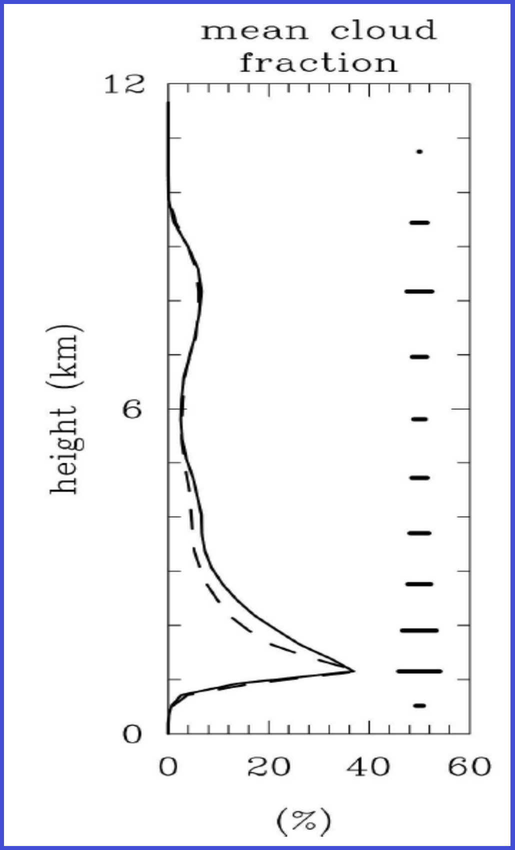
Cloud water and drizzle/rain water fields

Solid: polluted
Dashed: pristine

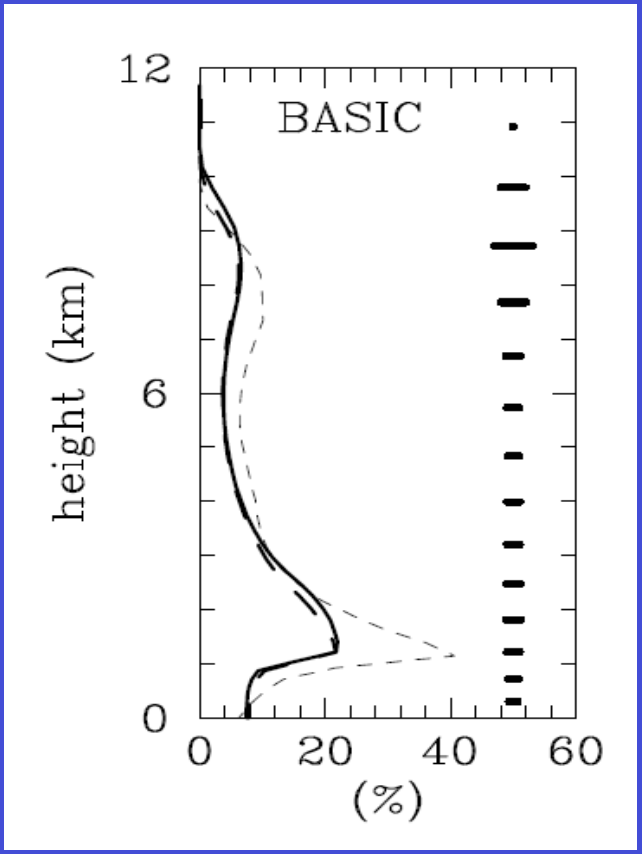
Ice field



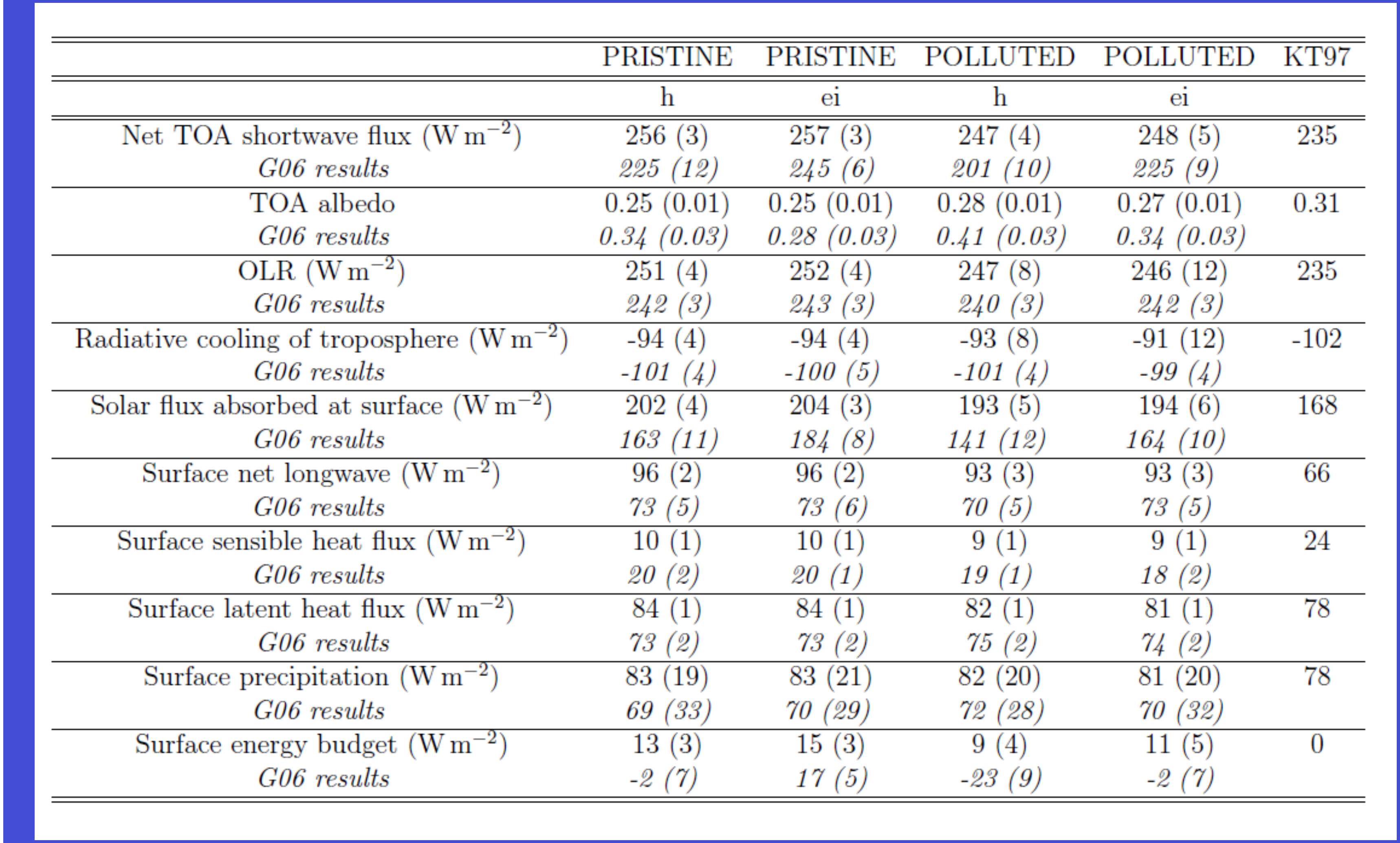
Grabowski
***J. Climate* 2006**



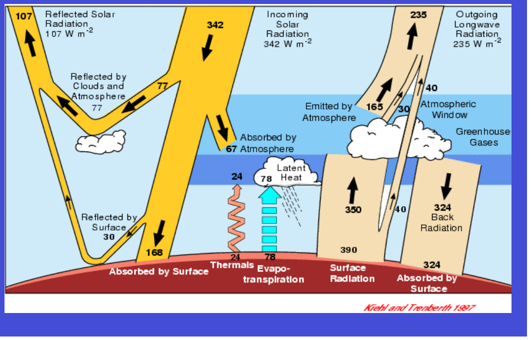
new
simulations



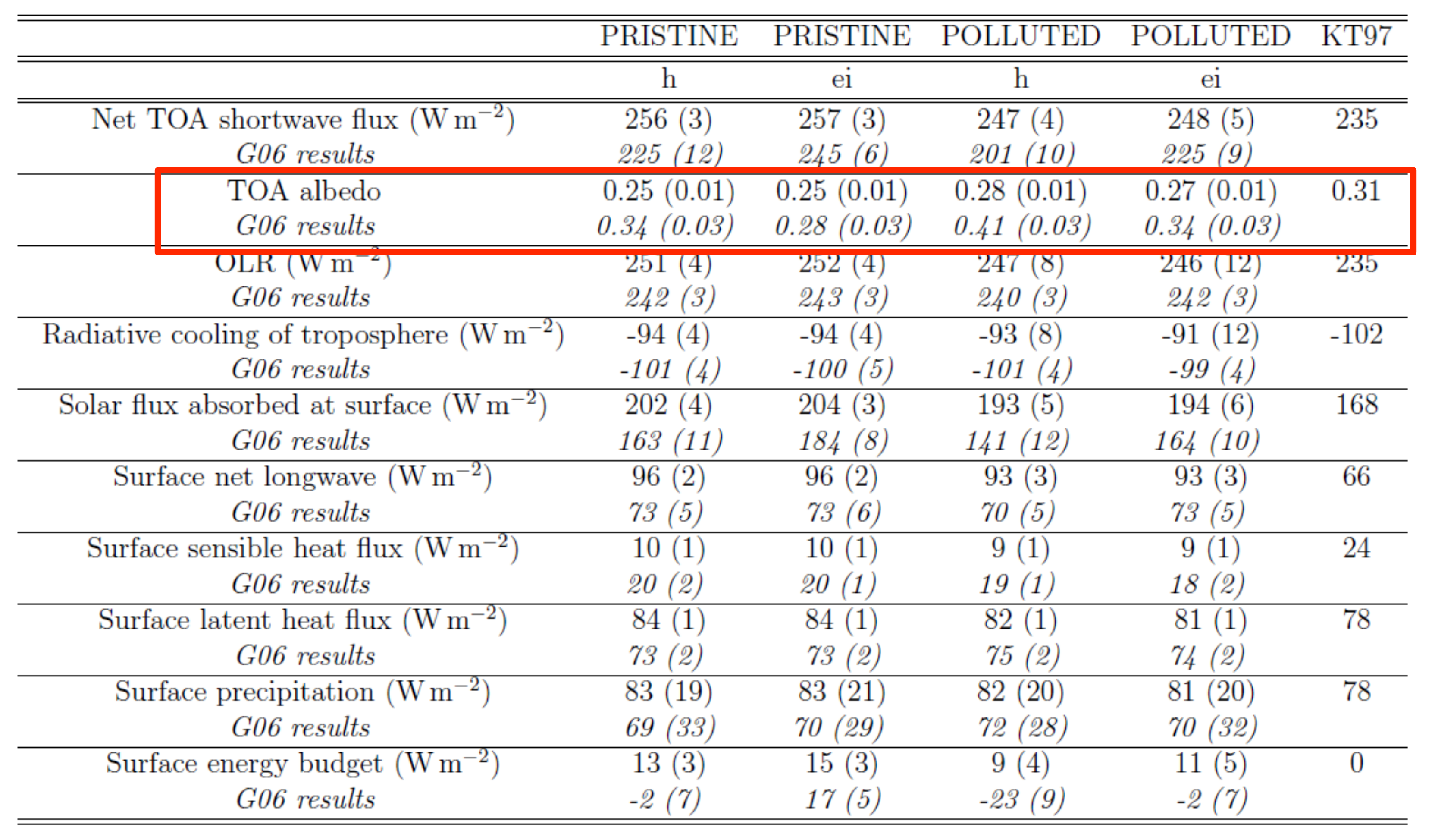
Solid: polluted
Dashed: pristine
Horizontal bars: standard deviation of temporal evolution
(measure of statistical significance of the difference)



	PRISTINE	PRISTINE	POLLUTED	POLLUTED	KT97
	h	ei	h	ei	
Net TOA shortwave flux (W m^{-2})	256 (3)	257 (3)	247 (4)	248 (5)	235
G06 results	*225 (12)*	*245 (6)*	*201 (10)*	*225 (9)*	
TOA albedo	0.25 (0.01)	0.25 (0.01)	0.28 (0.01)	0.27 (0.01)	0.31
G06 results	*0.34 (0.03)*	*0.28 (0.03)*	*0.41 (0.03)*	*0.34 (0.03)*	
OLR (W m^{-2})	251 (4)	252 (4)	247 (8)	246 (12)	235
G06 results	*242 (3)*	*243 (3)*	*240 (3)*	*242 (3)*	
Radiative cooling of troposphere (W m^{-2})	-94 (4)	-94 (4)	-93 (8)	-91 (12)	-102
G06 results	*-101 (4)*	*-100 (5)*	*-101 (4)*	*-99 (4)*	
Solar flux absorbed at surface (W m^{-2})	202 (4)	204 (3)	193 (5)	194 (6)	168
G06 results	*163 (11)*	*184 (8)*	*141 (12)*	*164 (10)*	
Surface net longwave (W m^{-2})	96 (2)	96 (2)	93 (3)	93 (3)	66
G06 results	*73 (5)*	*73 (6)*	*70 (5)*	*73 (5)*	
Surface sensible heat flux (W m^{-2})	10 (1)	10 (1)	9 (1)	9 (1)	24
G06 results	*20 (2)*	*20 (1)*	*19 (1)*	*18 (2)*	
Surface latent heat flux (W m^{-2})	84 (1)	84 (1)	82 (1)	81 (1)	78
G06 results	*73 (2)*	*73 (2)*	*75 (2)*	*74 (2)*	
Surface precipitation (W m^{-2})	83 (19)	83 (21)	82 (20)	81 (20)	78
G06 results	*69 (33)*	*70 (29)*	*72 (28)*	*70 (32)*	
Surface energy budget (W m^{-2})	13 (3)	15 (3)	9 (4)	11 (5)	0
G06 results	*-2 (7)*	*17 (5)*	*-23 (9)*	*-2 (7)*	



Kiehl and Trenberth 1997



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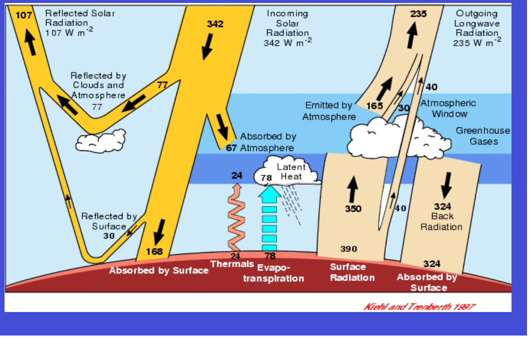
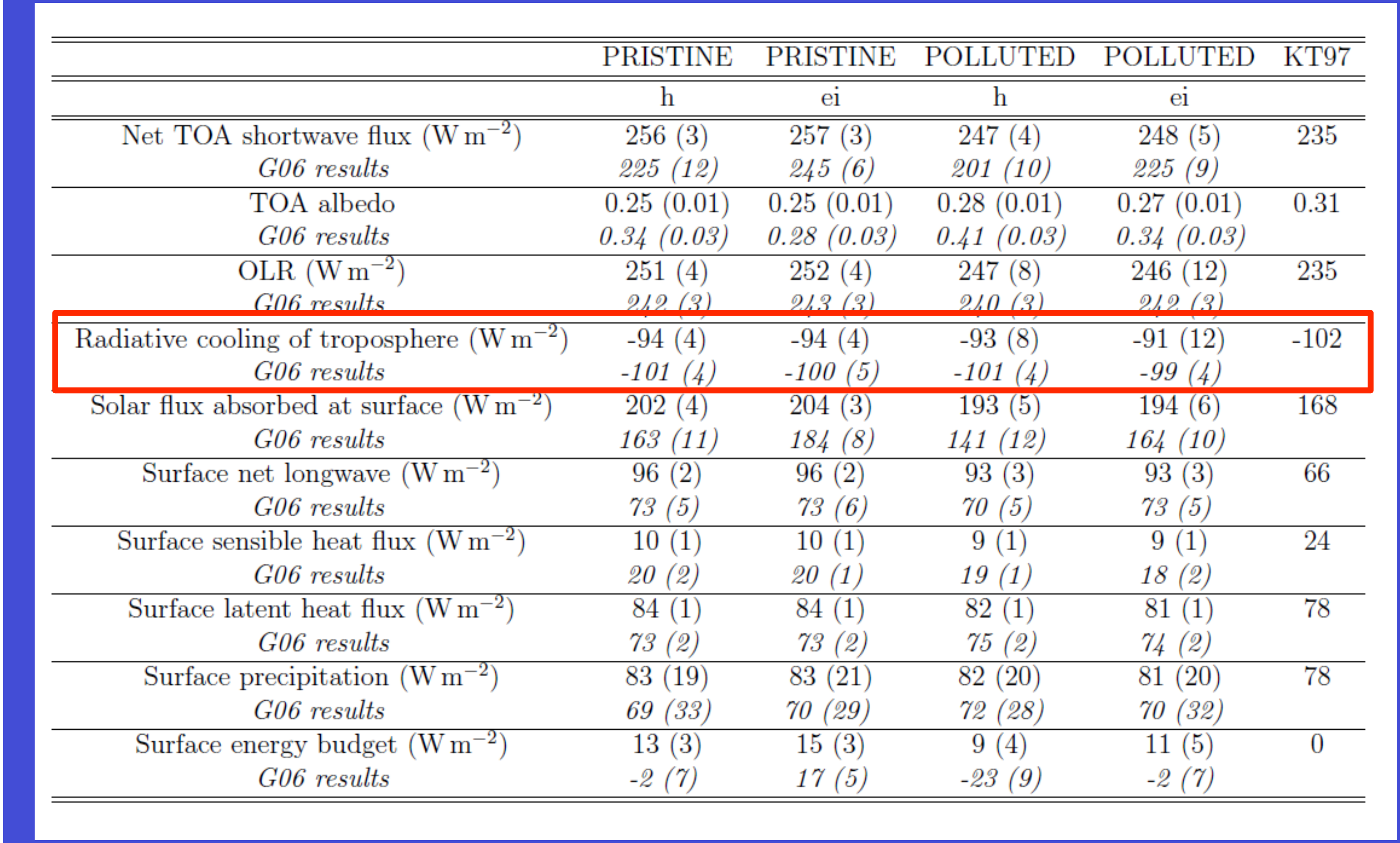


Kiehl and Trenberth 1997



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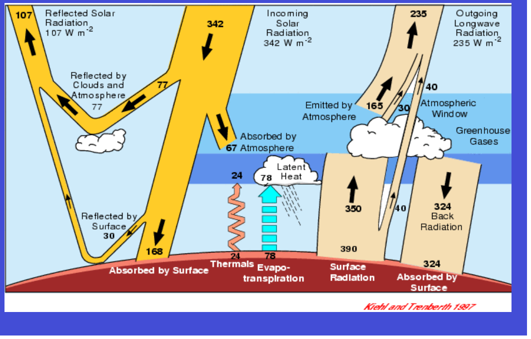

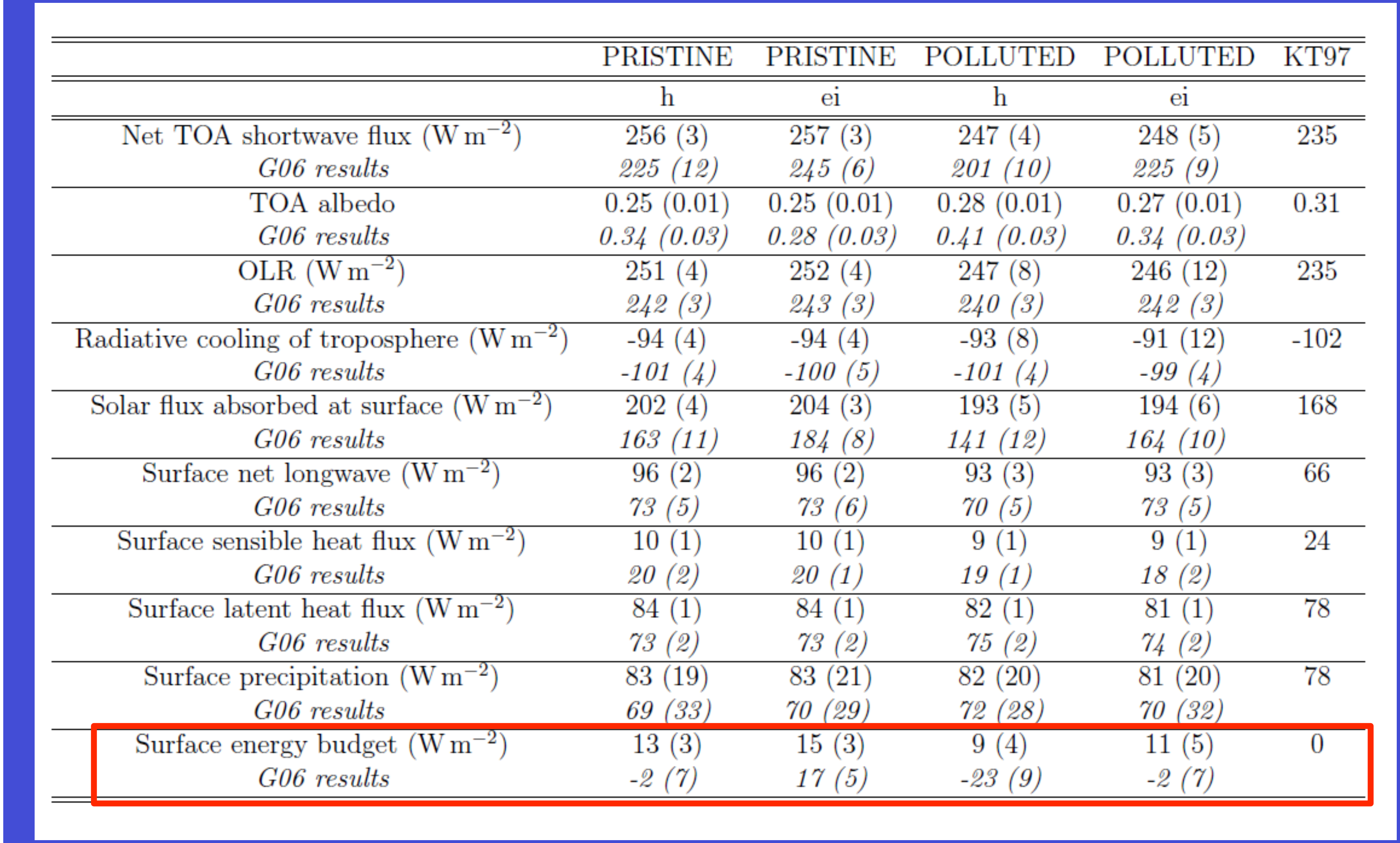

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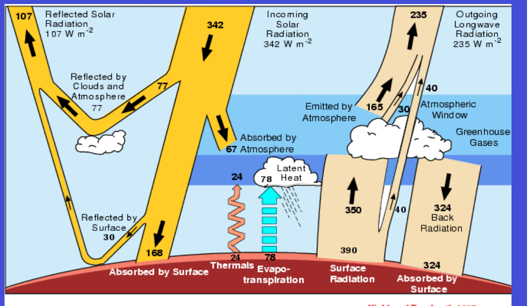

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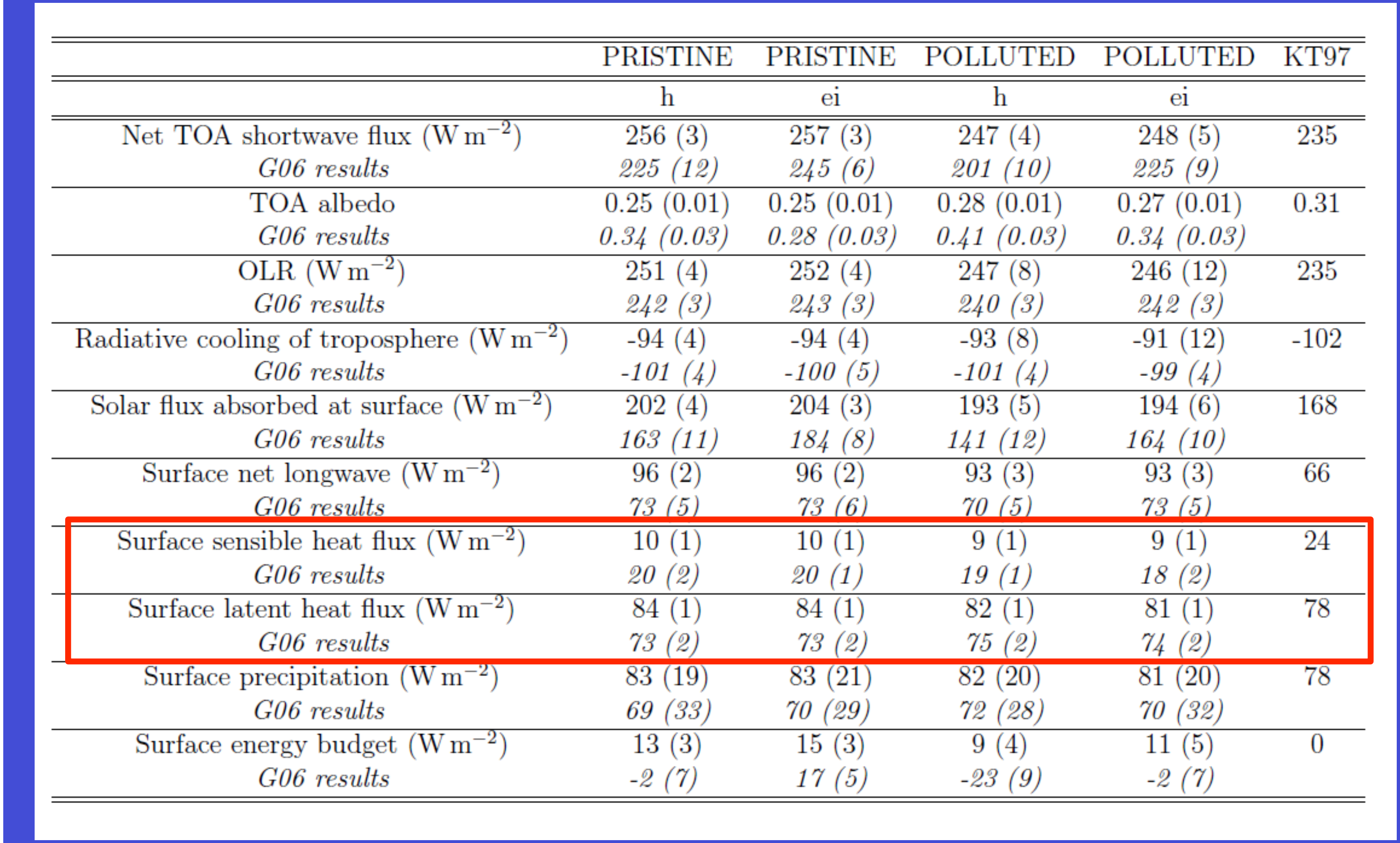

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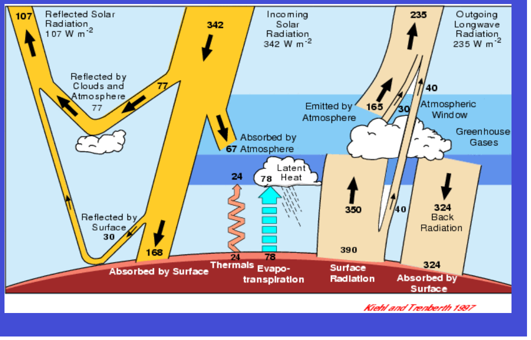

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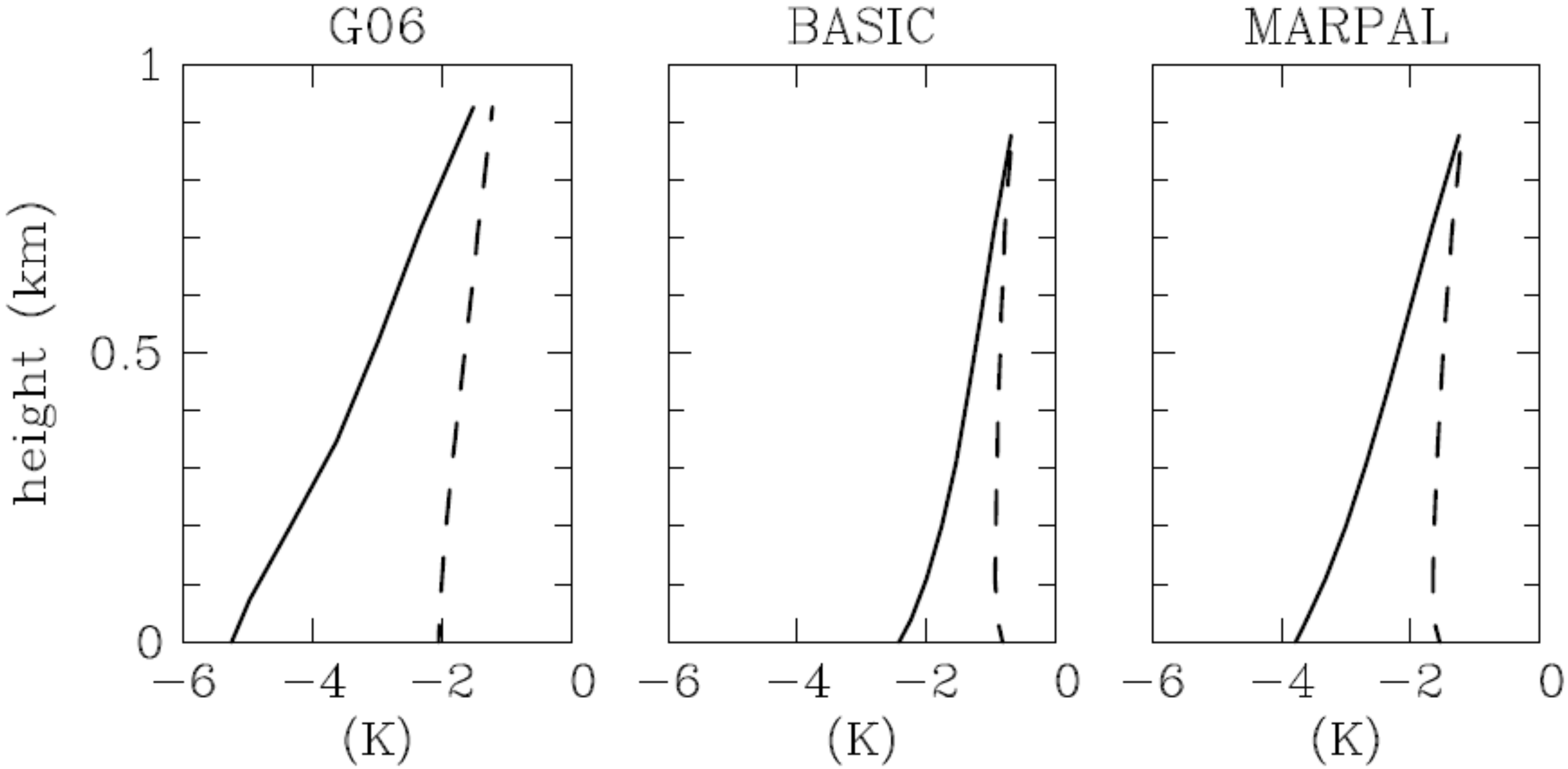
G06
BASIC
MARPAL
height (km)
1
0.5
0
−6
−4
−2
0
(K)

- *An idealized convective-radiative quasi-equilibrium simulations* ***using the double-moment bulk microphysics result in the mean atmospheric state similar to previous simulations with single-moment microphysics. The radiative cooling across the troposphere and the Bowen ratio for surface fluxes are different between old and new simulations.***

Radiative cooling: ***slightly lower tropospheric water vapor in the new simulations.***

Bowen ratio: ***double-moment microphysics has a different impact on cold-pool temperature and moisture due to smaller rate of rain evaporation.***

Difference ***between PRISTINE and POLLUTED is down to about 4 Wm^{-2} from about 20 Wm^{-2} in single-moment simulations.***