Global Energy Policy Research | GEPR

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?? ?? · Wednesday, February 23rd, 2022

NicoElNino/iStock

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?????????????????????????????????Mauritsen 2019?Mauritsen 2020)???

?1????????????????ECHAM6.1?2013??IPCC?????????????????????????ECHAM6.2??????????????3.5??????7????????????

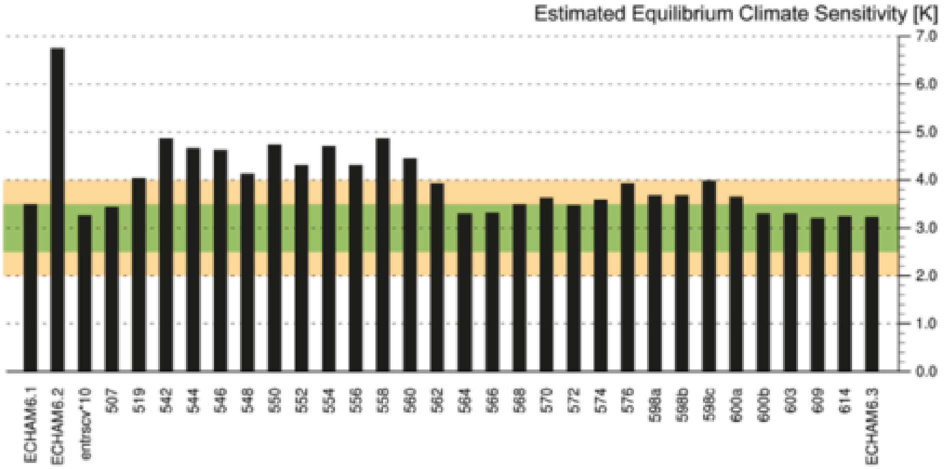

Figure 2. Evolution of estimated ECS using equation (1) as it was monitored during the development from ECHAM6.1 to ECHAM6.3. Three-digit numbers are shortened MPI-internal experiment identifiers, for example, mbe0507. Green and yellow bands show our target acceptance ranges which are centered at 3 K as discussed in section 2. Notes taken during experimentation documenting the settings and feedback in each experiment is provided in supporting information Tables S1–S4.

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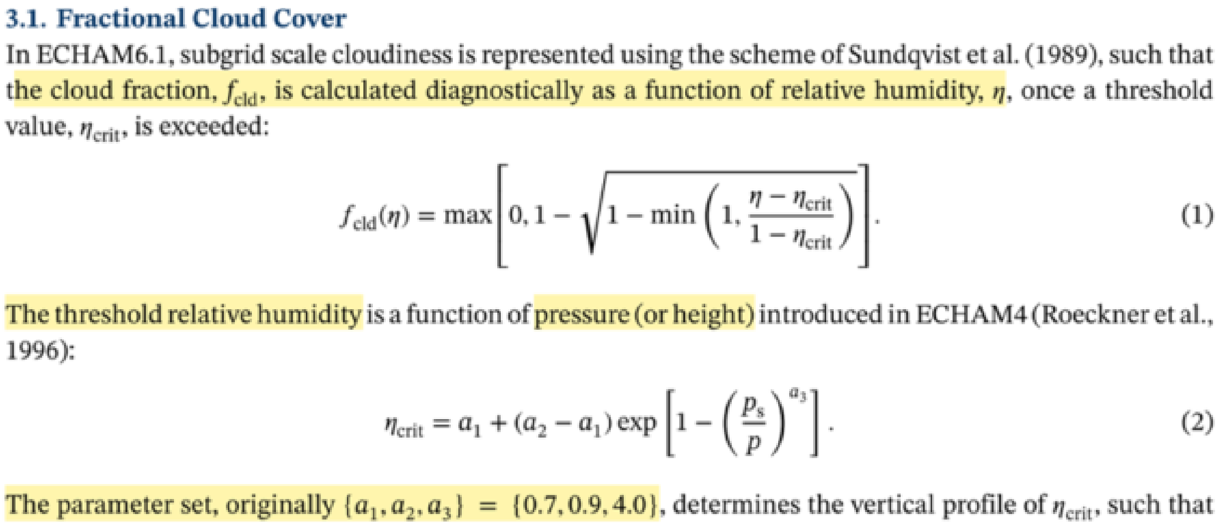

3.1. Fractional Cloud Cover

In ECHAM6.1, subgrid scale cloudiness is represented using the scheme of Sundqvist et al. (1989), such that the cloud fraction, f_{cld}, is calculated diagnostically as a function of relative humidity, η, once a threshold value, η_{crit}, is exceeded:

$$f_{\text{cld}}(\eta) = \max\left[0, 1 - \sqrt{1 - \min\left(1, \frac{\eta - \eta_{\text{crit}}}{1 - \eta_{\text{crit}}}\right)}\right]. \tag{1}$$

The threshold relative humidity is a function of pressure (or height) introduced in ECHAM4 (Roeckner et al., 1996):

$$\eta_{\text{crit}} = a_1 + (a_2 - a_1)\exp\left[1 - \left(\frac{p_s}{p}\right)^{a_3}\right]. \tag{2}$$

The parameter set, originally $\{a_1, a_2, a_3\} = \{0.7, 0.9, 4.0\}$, determines the vertical profile of η_{crit}, such that

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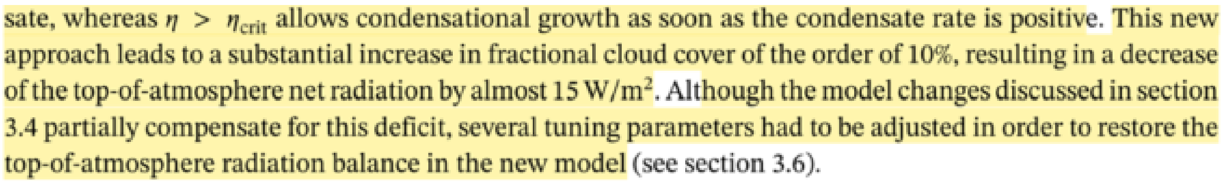

sate, whereas $\eta > \eta_{crit}$ allows condensational growth as soon as the condensate rate is positive. This new approach leads to a substantial increase in fractional cloud cover of the order of 10%, resulting in a decrease of the top-of-atmosphere net radiation by almost 15 W/m^2. Although the model changes discussed in section 3.4 partially compensate for this deficit, several tuning parameters had to be adjusted in order to restore the top-of-atmosphere radiation balance in the new model (see section 3.6).

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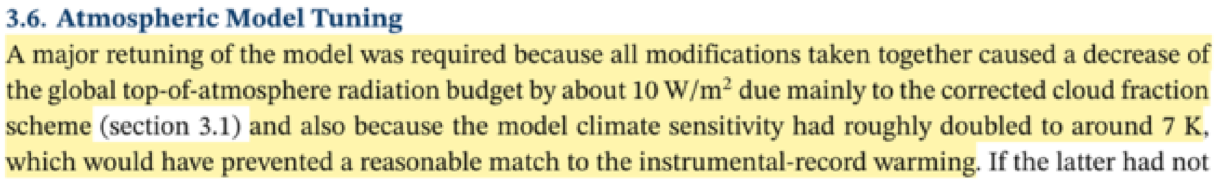

3.6. Atmospheric Model Tuning

A major retuning of the model was required because all modifications taken together caused a decrease of the global top-of-atmosphere radiation budget by about 10 W/m^2 due mainly to the corrected cloud fraction scheme (section 3.1) and also because the model climate sensitivity had roughly doubled to around 7 K, which would have prevented a reasonable match to the instrumental-record warming. If the latter had not

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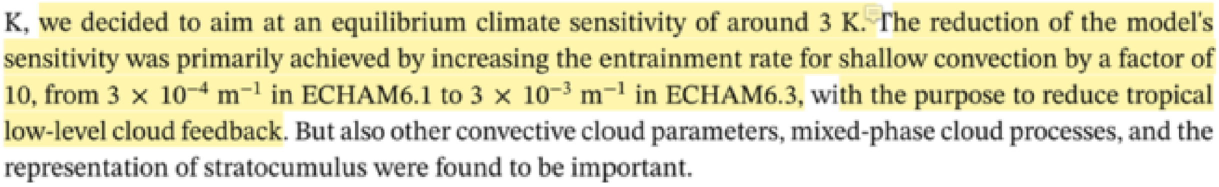

K, we decided to aim at an equilibrium climate sensitivity of around 3 K. The reduction of the model's sensitivity was primarily achieved by increasing the entrainment rate for shallow convection by a factor of 10, from 3×10^{-4} m^{-1} in ECHAM6.1 to 3×10^{-3} m^{-1} in ECHAM6.3, with the purpose to reduce tropical low-level cloud feedback. But also other convective cloud parameters, mixed-phase cloud processes, and the representation of stratocumulus were found to be important.

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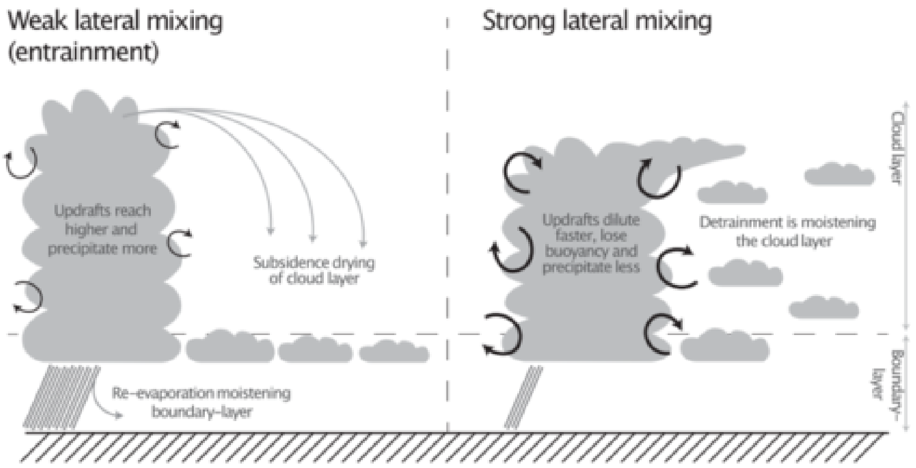

Figure 3. Illustration of the influence of shallow convection lateral entrainment and detrainment on the vertical distribution of clouds. With weak lateral mixing (entrainment, left) as in ECHAM6.2 shallow convective updrafts are less diluted with environmental air and therefore reach higher before losing buoyancy. As a consequence they precipitate more efficiently and act to dry the cloud layer. With stronger lateral mixing as in ECHAM6.3 more humidity is detrained into the cloud layer where as a consequence cloud layers can form. Also, the stronger mixing means the convective updraft loses buoyancy faster and therefore precipitates less efficiently.

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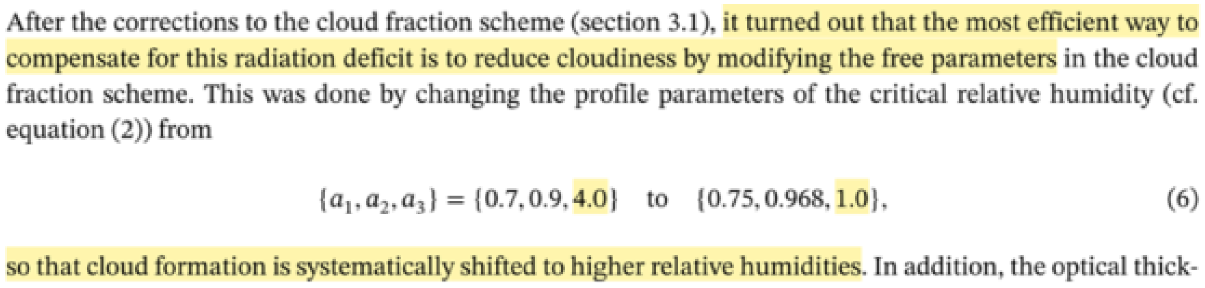

After the corrections to the cloud fraction scheme (section 3.1), it turned out that the most efficient way to compensate for this radiation deficit is to reduce cloudiness by modifying the free parameters in the cloud fraction scheme. This was done by changing the profile parameters of the critical relative humidity (cf. equation (2)) from

$$\{a_1, a_2, a_3\} = \{0.7, 0.9, 4.0\} \quad \text{to} \quad \{0.75, 0.968, 1.0\}, \tag{6}$$

so that cloud formation is systematically shifted to higher relative humidities. In addition, the optical thick-

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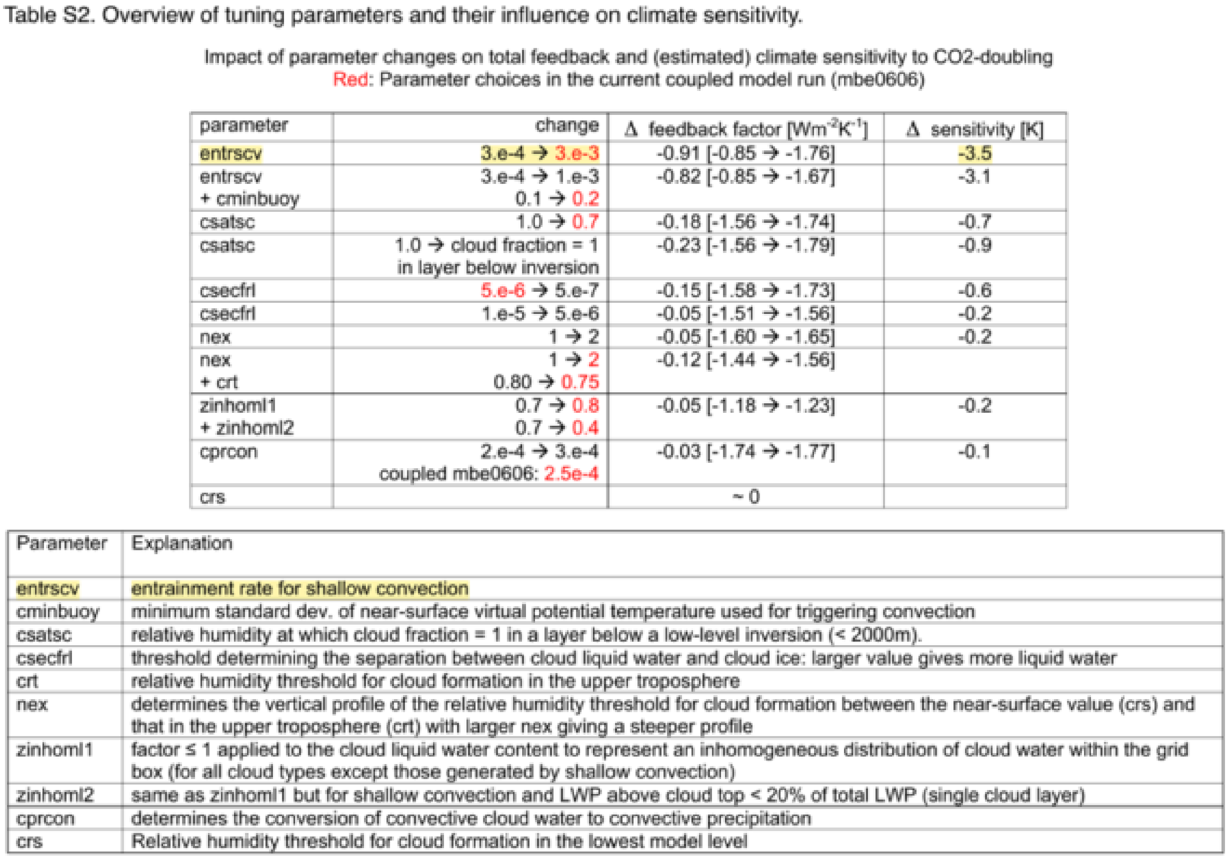

Table S2. Overview of tuning parameters and their influence on climate sensitivity.

Impact of parameter changes on total feedback and (estimated) climate sensitivity to CO2-doubling
Red: Parameter choices in the current coupled model run (mbe0606)

parameter	change	Δ feedback factor [Wm^{-2}K^{-1}]	Δ sensitivity [K]
entrscv	3.e-4 → 3.e-3	-0.91 [-0.85 → -1.76]	-3.5
entrscv + cminbuoy	3.e-4 → 1.e-3 0.1 → 0.2	-0.82 [-0.85 → -1.67]	-3.1
csatsc	1.0 → 0.7	-0.18 [-1.56 → -1.74]	-0.7
csatsc	1.0 → cloud fraction = 1 in layer below inversion	-0.23 [-1.56 → -1.79]	-0.9
csecfrl	5.e-6 → 5.e-7	-0.15 [-1.58 → -1.73]	-0.6
csecfrl	1.e-5 → 5.e-6	-0.05 [-1.51 → -1.56]	-0.2
nex	1 → 2	-0.05 [-1.60 → -1.65]	-0.2
nex + crt	1 → 2 0.80 → 0.75	-0.12 [-1.44 → -1.56]	
zinhoml1 + zinhoml2	0.7 → 0.8 0.7 → 0.4	-0.05 [-1.18 → -1.23]	-0.2
cprcon	2.e-4 → 3.e-4 coupled mbe0606: 2.5e-4	-0.03 [-1.74 → -1.77]	-0.1
crs		~ 0	

Parameter	Explanation
entrscv	entrainment rate for shallow convection
cminbuoy	minimum standard dev. of near-surface virtual potential temperature used for triggering convection
csatsc	relative humidity at which cloud fraction = 1 in a layer below a low-level inversion (< 2000m).
csecfrl	threshold determining the separation between cloud liquid water and cloud ice: larger value gives more liquid water
crt	relative humidity threshold for cloud formation in the upper troposphere
nex	determines the vertical profile of the relative humidity threshold for cloud formation between the near-surface value (crs) and that in the upper troposphere (crt) with larger nex giving a steeper profile
zinhoml1	factor ≤ 1 applied to the cloud liquid water content to represent an inhomogeneous distribution of cloud water within the grid box (for all cloud types except those generated by shallow convection)
zinhoml2	same as zinhoml1 but for shallow convection and LWP above cloud top < 20% of total LWP (single cloud layer)
cprcon	determines the conversion of convective cloud water to convective precipitation
crs	Relative humidity threshold for cloud formation in the lowest model level

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