Review for ACP

Title: Cirrus cloud thinning using a more physically-based ice microphysics scheme in the ECHAM-HAM GCM
Author(s): Colin Tully et al.
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General Comments:

This study is well organized and the paper is well written, with a comprehensive introduction. However, the results cannot be taken seriously in my opinion due to the treatment of vertical motions in the ECHAM-HAM GCM simulations. At the bottom of p. 6 and top of p. 7, the paper states that "The adiabatic cooling rate is determined by the vertical velocity, which is represented by a grid-mean value plus a turbulent component based on the turbulent kinetic energy (TKE), (Kuebbeler et al., 2014). Orographic effects on vertical velocity as well as small-scale gravity waves (Kärcher et al., 2006; Joos et al., 2010; Jensen et al., 2016a) in the upper troposphere are not included in this study." Why was the contribution of orographic effects on vertical velocity (w) ignored? As shown in Joos et al. (2008, JGR), outside the tropics over land, this orographic component is the dominant component (i.e., it is much greater than the combined large scale motion component and the TKE component that are the only components considered in this study). Ignoring this orographic component will greatly diminish the global contribution of homogeneous ice nucleation (henceforth hom) to cirrus cloud microphysics, rendering the results of this study a mere modeling exercise that ignores the main driving force responsible for the potential efficacy of CCT. Claiming relevance to CCT therefore appears misguided.

The authors must be familiar with the NASEM report "Reflecting Sunlight" that recommends federal funding for research on SAI, MCB and CCT? In this report on p. 49 it states: "Relative to SAI and MCB, CCT has received relatively less attention, and there is relatively higher uncertainty, due to uncertainty in the current fraction of cirrus formed through homogeneous versus heterogeneous nucleation (Cziczo et al., 2013; Gryspeerdt et al., 2018; Krämer et al., 2016; Mitchell et al., 2016; Mitchell et al., 2018; Sourdeval et al., 2018) ...". Four of the six references cited here provide strong evidence from satellite remote sensing that hom strongly affects the microphysical properties of cirrus clouds over mountainous terrain (and considerably downwind as well). Gasparini and Lohmann (2016, JGR) included the mountain-induced gravity wave parameterization described in Joos et al. (2008, JGR) and Kuebbeler et al. (2014, ACP) for estimating w. In view of this, why was this w contribution ignored in the current study? Evidence relating this orographic component of w to cirrus cloud microphysics and hom is described below.

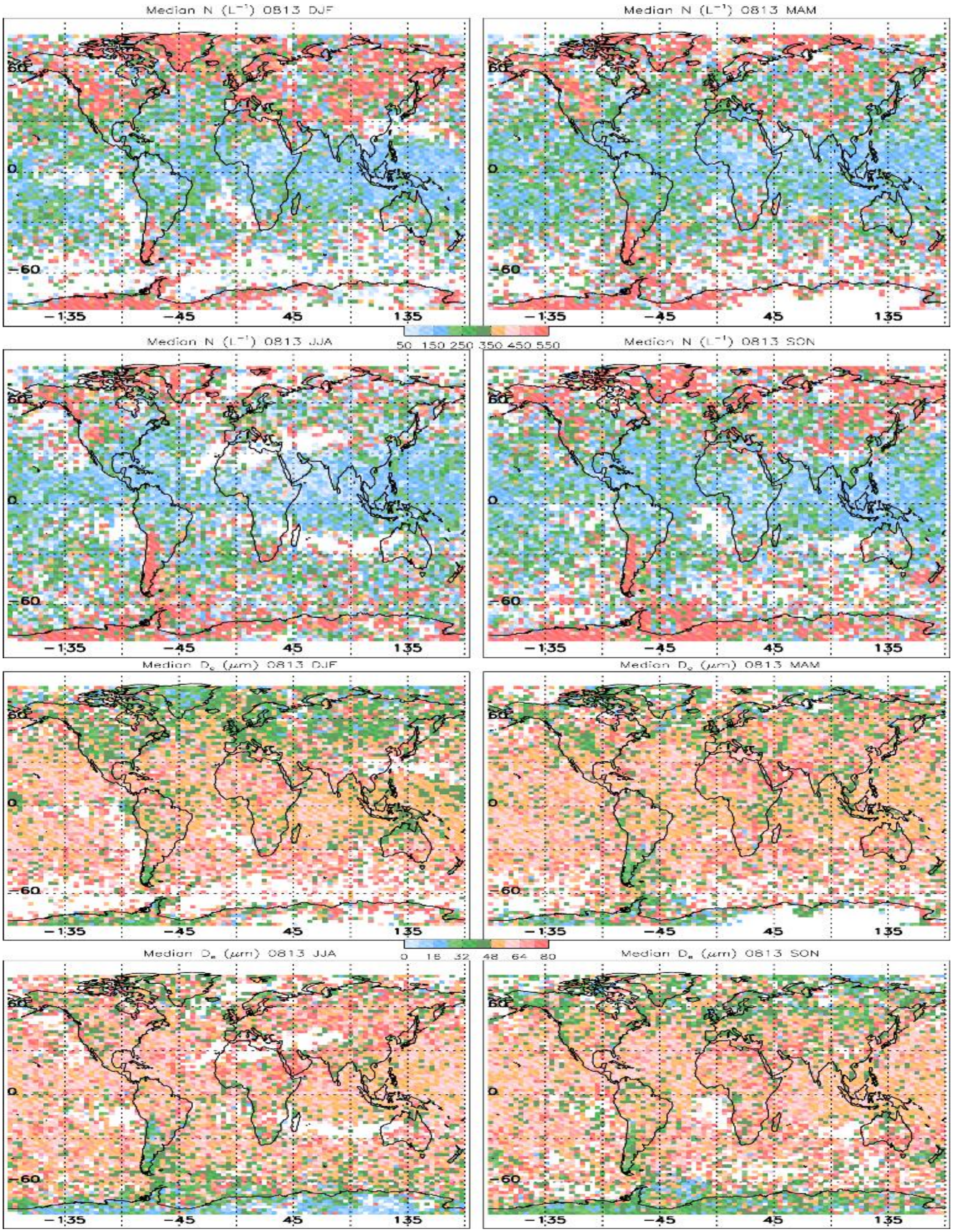

Figure 1. Vertically integrated CALIPSO satellite retrievals of cirrus cloud N_i (top 4 panels) and D_e (bottom 4 panels) for each season using the method of Mitchell et al. (2018).

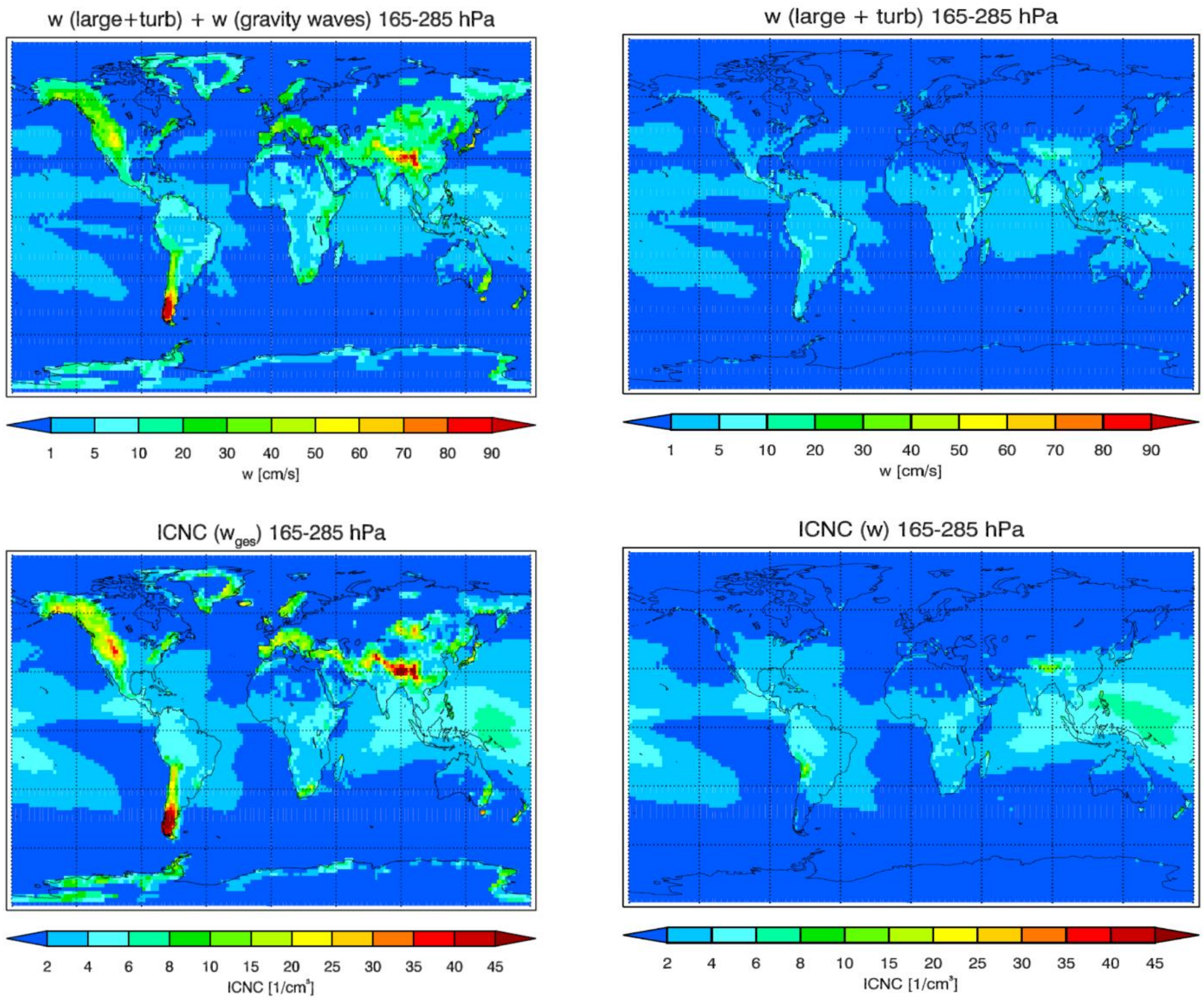

Figure 2. Taken from Joos et al. (2008) showing the impact of mountain-induced gravity waves on atmospheric vertical velocities and N_i (i.e., ICNC) when ice formation is through hom only.

Figure 1 shows CALIPSO satellite retrieval results based on Mitchell et al. (2018, ACP) for the years 2008 and 2013 for single-layer cirrus clouds (T < -38^{o}C or 235 K) for winter (DJF), spring (MAM), summer (JJA) and fall (SON), where cirrus cloud optical depth (OD) ranges between ~ 0.3 and 3.0. This OD category was most frequently observed in the satellite remote sensing study of Hong and Liu (2015, J. Climate) and the cloud radiative effect (CRE) for this OD category was most representative for cirrus clouds overall (Hong and Liu, 2016, J. Climate). The upper four panels are for the median ice particle number concentration N_i while the lower four panels are for the median effective diameter D_e. Legends for size (µm) and concentration (L^{-1}) are shown at centers. The uncertainty in N_i is about a factor of 2 with N_i biased high in this version of the retrieval (which yields the best agreement with in situ observations of D_e). The regions having higher N_i and smaller D_e in the CALIPSO retrievals are likely to be more affected by hom. Accordingly, the relative contribution of heterogeneous ice nucleation (henceforth het) and hom to N_i and D_e would depend on topography and season. The relatively high N_i in the Polar Regions may be partly due to anomalously low INP concentrations, allowing hom to occur more frequently.

It is noteworthy that the N_i retrievals shown in Fig. 1 are qualitatively consistent with those reported in Sourdeval et al. (2018, ACP) and Gryspeerdt et al. (2018, ACP), although they differ in absolute magnitude. That is, the relative changes in N_i outside the tropics with orography and season are consistent, with N_i higher over mountainous regions and higher during winter.

Figure 2 shows ECHAM5 model simulations from Joos et al. (2008, JGR) based only on hom at cirrus cloud levels (165 – 285 hPa). The left panels show vertical motions (w) and ice crystal number concentrations (ICNC) where w is based on large scale motions, turbulence (TKE) and mountain-induced gravity waves. The right panels show w and ICNC where w is only based on large scale and TKE motions. ICNC is in cm^{-3} since hom produces relatively high concentrations.

It is seen from pattern recognition that w and ICNC (i.e., N_i) in Fig. 2 are strongly correlated. Comparing with the CALIPSO retrieval results, a close relative correspondence is also found between the N_i pattern in Fig. 2 based partly on gravity waves and the CALIPSO N_i in Fig. 1, especially during non-summer seasons. This strongly suggests that orographic gravity waves (the largest of the three w components outside the tropics over land) are responsible for this correspondence since they sufficiently increase w for hom to activate, thus producing higher N_i. That is, the relative humidity with respect to ice, RHi, must exceed some threshold (RHi > 145%) for hom to activate, and this can only be achieved when w is sufficiently high.

The seasonal behavior of N_i and D_e in Fig. 1 has been described in Joos et al. (2014, ACP) through the seasonal behavior of hom and het over mountainous terrain. When the temperature profile for the simulated orographic cirrus cloud was increased by 20 K (from 210 K at 9 km to 230 K at 9 km) and only hom was active, N decreased by roughly a factor of 20. When both hom and het were active (ice nucleating particle or INP concentration of 10 L^{-1}), hom was effectively turned off in the warmer simulation with N ~ 1 L^{-1}, but hom was still very active in the cold simulation where N exceeded ~ 2000 L^{-1}. This was largely due to higher vapor depletion rates by ice at warmer temperatures, preventing RHi from reaching the hom threshold. The seasonal changes in Fig. 1 may be partially explained in this way.

In addition to the above studies, another GCM study by Barahona et al. (2017, Nature) provides very similar findings. That study simulated hom and het in cirrus clouds using a GCM at 100 km horizontal resolution. However, standard deviations in vertical velocities (w), σ_w, were calculated at 7 km horizontal resolution in a separate simulation to drive ice nucleation processes in the lower resolution simulation. In this way the competition between hom and het may be achieved more realistically due to more realistic σ_w. Note that σ_w is proportional to w. Results from that study are shown in Figs. 3 and 4 below. Figure 3 is very similar to the upper left panel in Fig. 2 (where the orographic w component is included). Figure 4 gives the relative frequency of cirrus events dominated by hom, which is similar to the lower left panel in Fig. 2 (N_i when the orographic w component is included) outside the tropics.

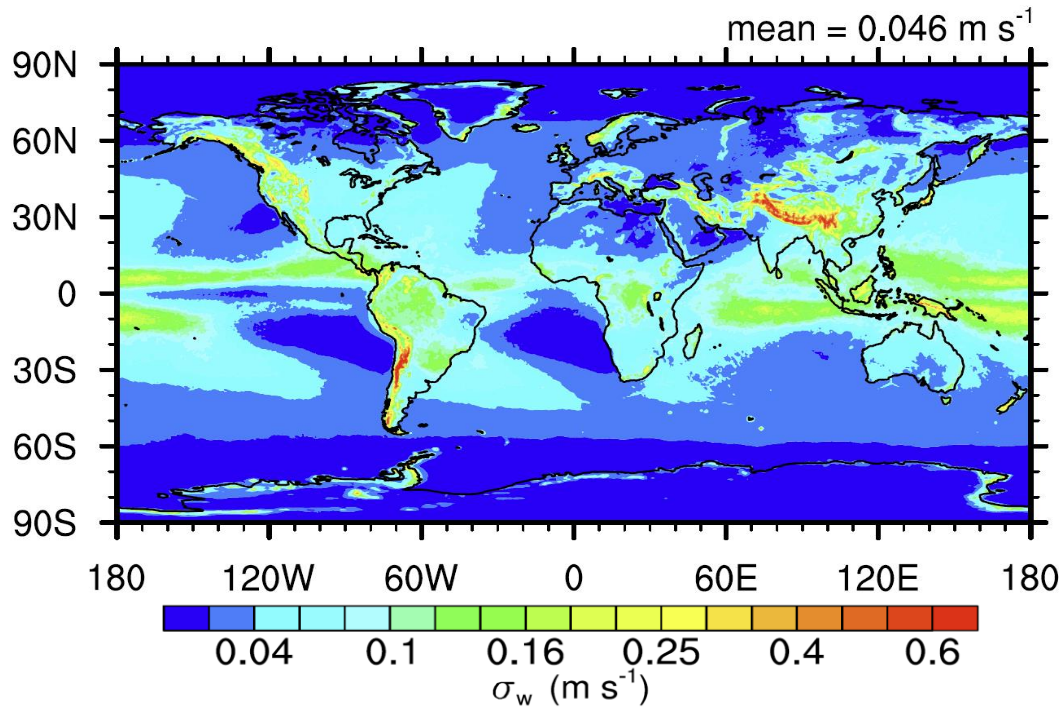

Figure 3. Taken from Barahona et al. (2017, Nature), showing annual mean σ_w calculated from 7 km resolution global output (note that w is proportional to σ_w).

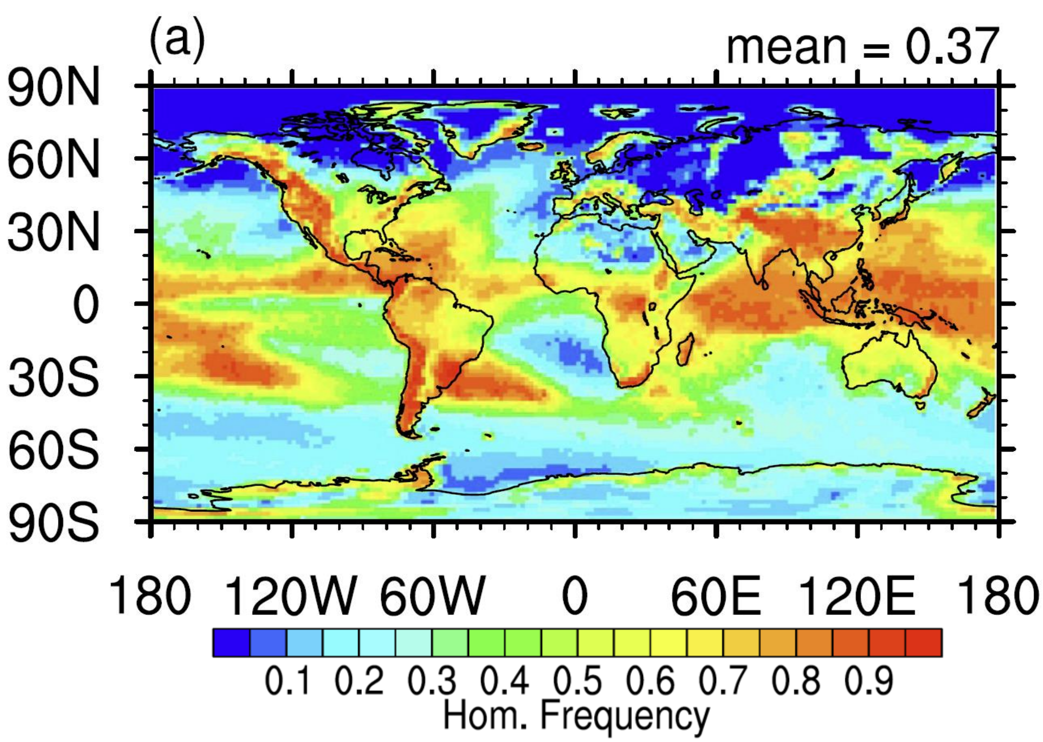

Figure 4. Taken from Barahona et al. (2017, Nature), showing the probability of hom globally based on σ_w.

To summarize, this cirrus cloud modeling study by Tully et al. uses the ECHAM6.3-HAM2.3 aerosol-climate GCM with w depending only on large scale and TKE motions, perhaps similar to those shown in the upper right panel of Fig. 2. This neglects the strong w contribution from mountain-induced gravity waves, causing hom to rarely activate (resulting in relatively low N_i). Since a realistic evaluation of CCT depends on a realistic treatment of hom, this paper should not be published in ACP. However, it could be revised with a realistic treatment of w. If the revision will require many months, I recommend rejecting this paper to allow the authors sufficient time to modify the GCM and study their new results. On the other hand, the GCM should already contain a w parameterization that includes orographic effects, such as used in Gasparini and Lohmann (2016, JGR). Thus, it might not take long to resubmit, in which case my recommendation would be “major revision”.

However, the authors should beware that the w treatment in Gasparini and Lohmann (2016, JGR) only predicts hom near the tropopause (~ 200 hPa), which may be largely why the CCT cooling effect in that study is negligible. Taking relatively high N_i as a proxy for hom, Fig. 9 in Mitchell et al. (2018) reveals that hom appears to be active throughout the vertical column for cirrus clouds; not just near the tropopause.

Major Comments:

Due to the fundamental flaw in the paper noted above, a detailed review of the model predictions did not seem warranted.

Sincerely,
David Mitchell

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