

Interactive comment on “Increase in the Frequency of Tropical Deep Convective Clouds with Global Warming” by Hartmut H. Aumann et al.

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We thank reviewer#2 for several penetrating comments.

1) ... If we assume DCC are such storms, then their frequency of occurrence should decrease slightly...

Response: The Clausius Clapeyron argument applies to mean values, but we are not so sure that conclusions for the mean apply to the extremes, the DCC, used in our study. The DCC are not typical large storms, but the severest form of thunder storm, where the cloud tops penetrate the tropopause in the area of the AIRS field of view (15x15 km) and larger. DCC are by far not the dominant source of the mean tropical rain fall. DCC cover only 0.6% of the tropical oceans (on any one day). They are

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associated with 3 mm/hr of rain (according AMSRe). Since the mean rain rate for the tropical ocean is 0.1mm/hr, they contribute $0.006 \cdot 3 / 0.1 = 18\%$ to the total tropical ocean rainfall. If the frequency of the DCC goes up by 50% in a warmer climate and if the associated rain rate is still 3mm/hr, then the contribution of the DCC to the total rain fall is 27%. This still is not the dominant source of mean rain fall, but not insignificant. There may be compensating effect, e.g. less shallow convection, in a warmer climate. Resolving this is a challenge for models. We hope that by getting this paper into the literature, we start the process.

2) The result (0.5 K/K) is challenging because models do not produce the reported result and because there seems to be little theoretical grounds for this.

Response: DCC are very difficult to model, even on the 1/4 degree grid used by ECMWF. There should be no expectation that evidence for DCCs should be seen in climate models due to their much lower spatial resolution than AIRS. However, there are indirect indicators related to vertical stability which do not follow the surface warming by 1K/K. The Moist Adiabatic Lapse Rate (MALR) at 300 hPa is a measure of vertical stability. As stated in the manuscript, the paper by Johnson and Xie (2010, Figure 2a in the paper and associated discussion) finds that MALR in the CMIP3 models has a convective adjustment of between 0.42-0.48 K/K. They claim that 0.43K/K is expected on theoretical grounds. Intuitively there should be a relationship between MALR and DCC, but it have not been established.

3) Methodology: Linear regression is usually used when one variable is much less noisy than the other and the less noisy variable is placed on the x-axis.

Response: Figure 2 shows that the mean SST (x-axis) is by far less “noisy” than the SST at $\frac{1}{2}$ peak. The mean SST on the x-axis are not random variables. The fact that there is any difference in the mean SST between the odd and even days is due to the fact that the SST for the tropical ocean is random sampled by only about 7,000 points per day.

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4) Methodology: A more sophisticated software would probably yield a slope closer to 1 K/K.

Response: We challenged the 0.5K/K result by using different algorithm, including dividing the data into odd and even days, rejecting the warmest two years (more on this further down) and having one of the coauthors repeat the analysis from scratch. The quoted results used the MATLAB toolbox (“out of the box”) because it is a traceable, transparent, simple linear least squares fit to the data. We tried REGRESS and PLSREGRESS from the MATLAB statistics toolbox. However, PLSREGRESS is a PCA type regression, which treats the x and y axis as random variables. This is not appropriate for our data and the result was rejected. (The PLSRERGES produced a slope of 0.11 K/K with 0.05 K/K slope uncertainty.) Nothing got the slope anywhere near 1K/K.

5) Conceptual: It is obvious the most of the signal contributing to the slope of 0.5K/K comes from the two warmest years, the 2015 and 2016 El Nino years. ... Perhaps then it is not surprising that the $\frac{1}{2}$ peak of the DCC distribution is not moving to warmer SST as fast as the tropical mean. ...

Response: The reviewer is correct that 2015 and 2016 are the warmest two years. We interpret “moving to warmer SST as fast as the tropical mean” implies 1 K/K. As a numerical experiment we removed the four data points where the mean tropical SST is warmer than 299.6 K. The slope decreased to 0.19K/K, but with a much larger 0.34K/K slope uncertainty. This is in the opposite direction of that expected by the reviewer. Even the mean plus one sigma is still far from 1 K/K.

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