Supporting Material for: Radiative feedbacks on land surface change and associated tropical precipitation shifts

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ABSTRACT

1. Imposed Albedo Changes vs. Albedo Changes Due to Snow/Ice Changes

The imposed change in albedo was a uniform decrease of 0.1 to the visible direct and visible diffuse streams of shortwave radiation. The near-infrared direct and diffuse albedos were unchanged between simulations. As such, the actual effective imposed change in albedo is less than 0.1. The area-weighted mean change in snow-free albedo is 0.05 (range: 0.047 to 0.052; figure 1 c,d)). The effective albedo change is not perfectly uniform, with slightly larger effective albedo changes in the tropics, reflecting spatial differences in the magnitude of shortwave radiation partitioned into each of the four streams represented by the land model (visible direct, visible diffuse, near-IR direct, and near-IR diffuse). Only albedo in the visible spectrum (both direct and diffuse) was perturbed in this study.

The total modelled change in albedo (annually averaged for clear-sky conditions) includes the albedo effects of changes in snow and ice cover (figure 1a). For each month of the simulation, we evaluate the total amount of snow in the grid cell. If the liquid water content of the snow is greater or equal to 0.25m, we consider that gridcell to be "snow covered". Using this time series of snow-covered gridcells, we can calculate the albedo change in each gridcell for both snow-covered and snow-free conditions (figure 1 b,c). The snow-free albedo change is used as our effective imposed change in albedo, $\Delta\alpha_i$. For instance, the effectively imposed albedo change of 0.05 $\Delta\alpha_i$ over non-glaciated high-latitude land areas (figure 1 c) is larger than the actual total modelled change in albedo $\Delta\alpha_m$, as the imposed albedo change is masked by snow for much of the year. Changes in snow cover (in response to decreased snow-free land albedo) themselves drive changes in albedo ($\Delta\alpha_s$; figure 1b).

a. Steps for calculating albedo and kernel-estimated SW

1. Modelled albedo is saved at a monthly timestep. This includes both the effect of the imposed snow-free albedo, as well as the effects of any snow cover modifying that albedo and any changes in sea ice modifying ocean albedo.

2. At ever month, a snow-mask is generated, where a gridcell is considered "snow-covered" if it contains ≥ 0.25m of snow-water equivalent.

3. A snow-mask time series is generated, which is used to create a corresponding time series of albedo for snow-free gridcells over land. series of albedo for snow-free gridcells (what about ice? its just over land that this happens, so no ocean is in this either. Just snow-free land albedo)

4. In this masked time series, the albedo is set to Nan over the high latitudes in winter when there is no insolation.

5. The mean of the above time series of snow-free albedo gives the effective imposed change in albedo, $\Delta\alpha_i$.

6. In order to account for changes in ice that contribute to the total modelled albedo change, the snow-free albedo time series has all Nan's replaced with zeros (this isn't done initially as it would artificially decrease the *imposed* albedo change in the high latitudes - at this step, the high-latitude Nan albedo change during winter is also set to zero).

7. An albedo feedback time series (to capture changes in snow and ice) is then generated by subtracting the effective imposed albedo time series (which is identical at each time step) from the time series of actual modelled change in albedo.

8. To get the forced albedo TOA SW response (resulting from the imposed change in albedo), we multiple the (Nan-free) snow-free imposed albedo time series (which is identical at every time step) by the clear-sky TOA radiative SW kernel for CAM5.

9. To get the albedo feedback TOA SW response, we multiply the snow-albedo time series (which includes albedo changes over the ocean due to ice) by the clear-sky TOA radiative SW kernel for CAM5.

10. The sum of the two kernel estimated change in TOA SW add up to the total modelled albedo change multplied by the kernel (as they should!)

References

Pendergrass, A. G., A. Conley, and F. M. Vitt, 2018: Surface and top-of-Atmosphere radiative feedback kernels for cesm-cam5. *Earth System Science Data*, **10 (1)**, 317–324, doi:10.5194/essd-10-317-2018.

LIST OF FIGURES

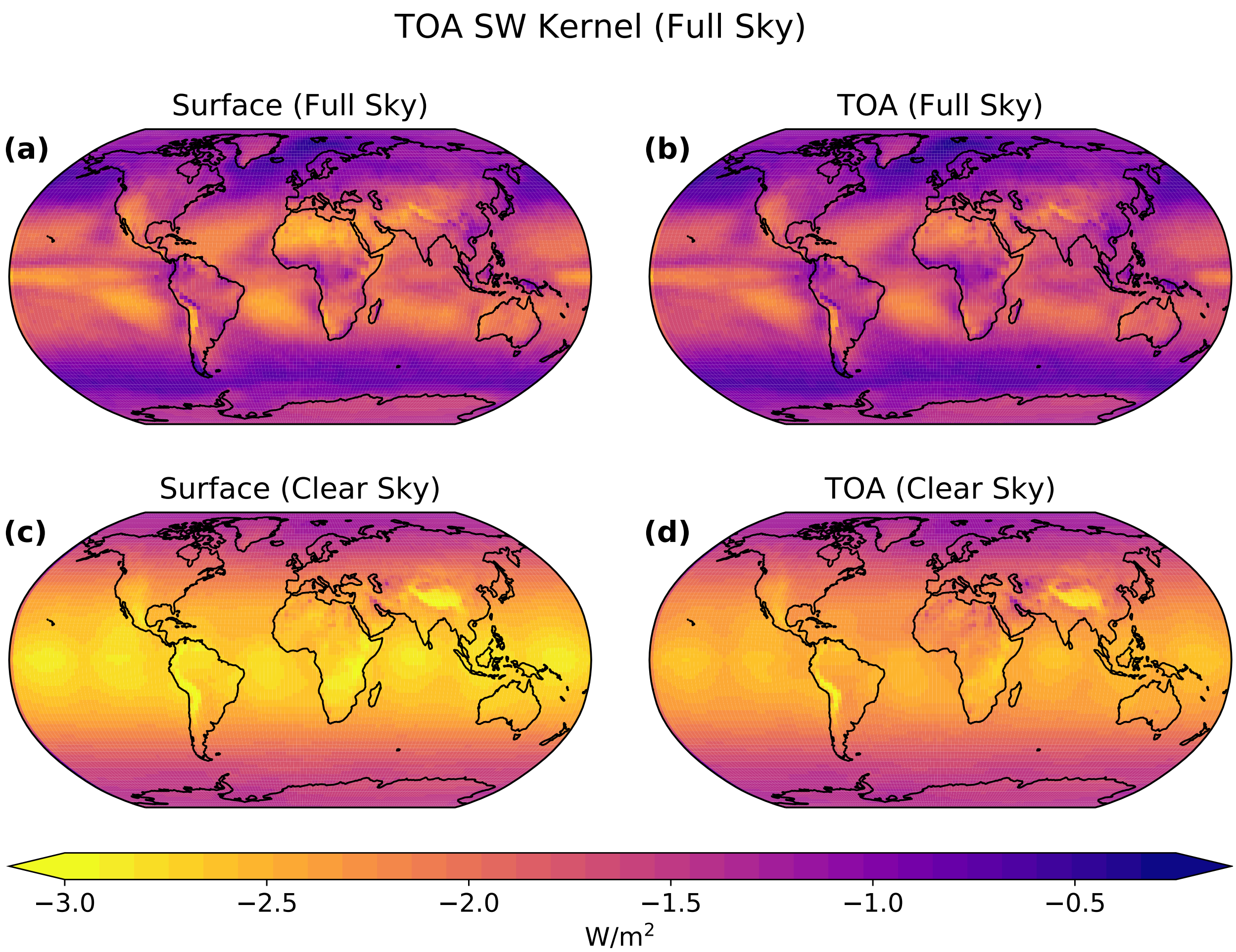

FIG. S1. The CAM5 full sky (a,b) and clear sky (c,d) shortwave kernel for the surface (a,c) and the TOA (b,d). Colors show the change in net SW radiation for a 1% increase in surface albedo at each gridcell (from Pendergrass et al. (2018)).

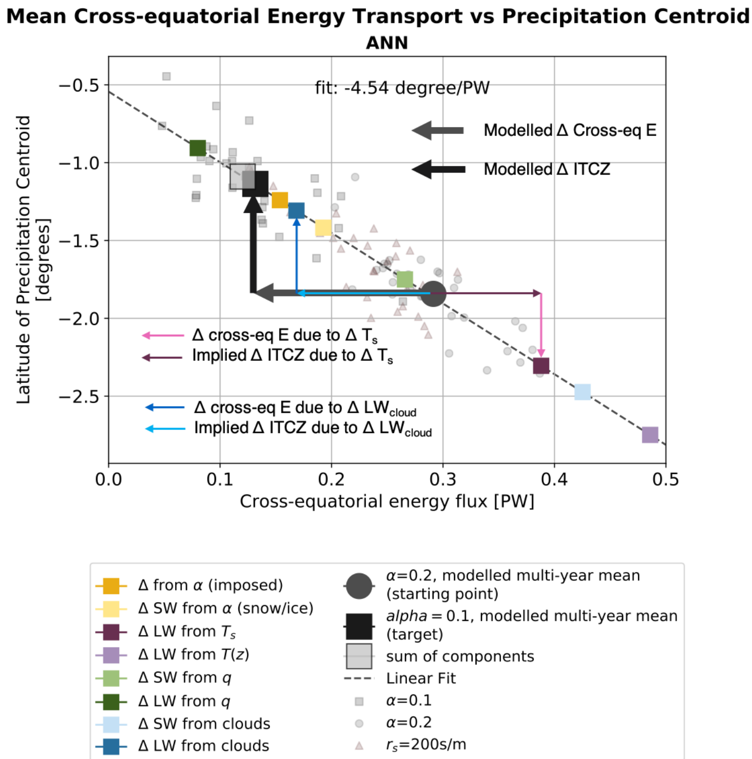

FIG. S2. Annotated version of figure 5a, showing how we go from a change in AET (attributed to an individual contribution to the total change in the TOA energy budget) to a corresponding shift in the zonal-mean ITCZ location (due to the same individual contributing component). For example, the change in T_s leads to a change in TOA_{net} that would drive an increased in AET_{eq}, and thus a southward shift in ϕ_p (purple square). In contrast, the imposed change in albedo (yellow square) would lead to a change in TOA_{net} that would decrease AET_{eq} and lead to a northward shift in ϕ_p. The combination of each individual component of the change in TOA_{net} yields the total modelled change in AET_{eq} and ϕ_p (black and gray squares).