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Effects of snow grain non-sph
sensitivity tests with

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Introduction

Snow grains are non-spherical and often irregular in shape. Still, they are often treated as spheres in radiative transfer calculations. Here**, we evaluate the effects of using non-spherical (NONSPH) instead of spherical (SPH) snow grains in the calculation of snow albedo in a climate model.** The experiments are made with the NorESM model in a mixed-layer ocean configuration. In the NONSPH case, the single-scattering properties of snow grains are based on a combination of three habits: severely rough (SR) droxtals, aggregates of SR plates and strongly distorted Koch fractals (Räisänen et al., Parameterization of single-scattering properties of snow, The Cryosphere, 9, 1277-1301). The main finding is that **while the instantaneous global-mean radiative effect of changing the snow grain shape is modest, it has a substantial impact on the climate simulated by NorESM**, owing to strong snow and sea ice feedbacks.

1. Instantaneous radiative effects

The use of non-spherical snow grains in the NONSPH experiment results in a higher snow broadband albedo, typically by 0.02-0.03 (**Fig. 1a**). This arises from the smaller asymmetry parameter g (enhanced sideward-/backward scattering) in the NONSPH case; for example in the visible region, g≈0.77-0.78 for NONSPH and g≈0.89 for SPH. The higher albedo in the NONSPH case gives rise to an instantaneous negative difference in the top-of-model net solar radiation (i.e., more radiation reflected back to space) (see **Fig. 1b**). In the global mean, this "radiative forcing" is modest (ΔF=-0.218 Wm^{-2}), although it is much larger at high latitudes and in Tibet.

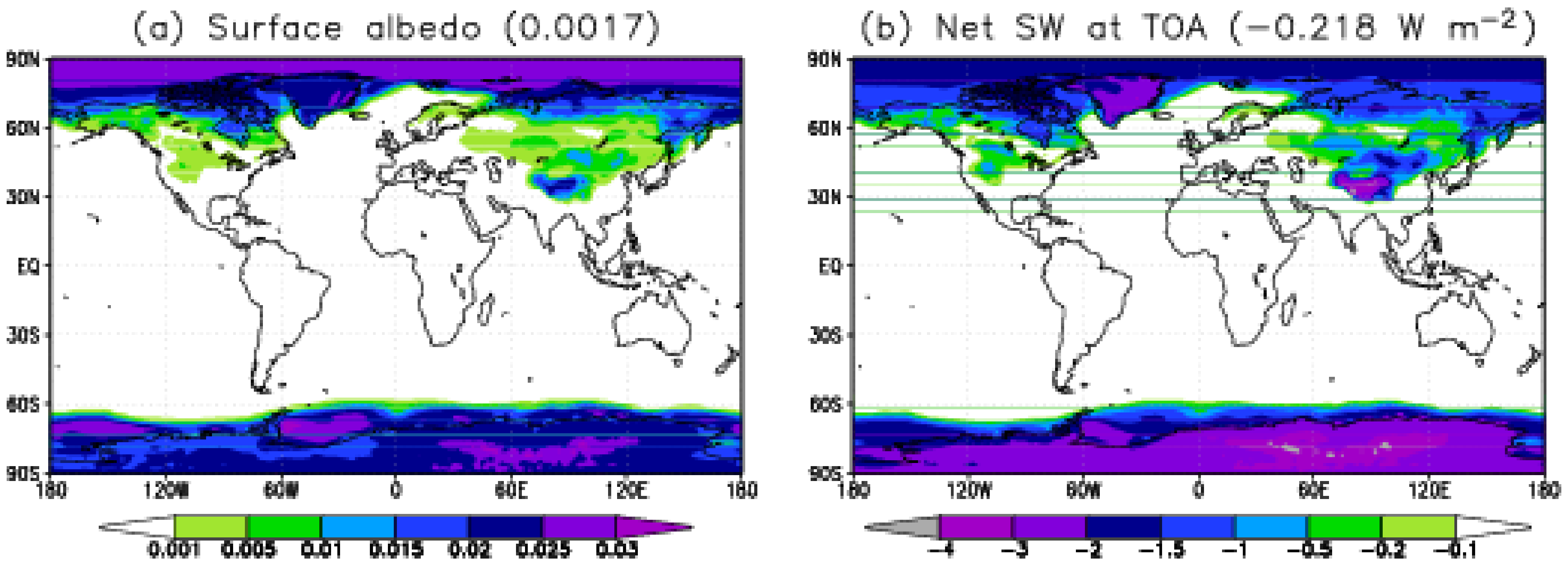

Fig. 1. The impact on **(a)** annual-mean surface albedo and **(b)** annual-mean top-of-the-model net shortwave radiation due to replacing spherical snow grains with non-spherical, evaluated through diagnostic radiation calculations in the SPH experiment. Global mean values are given in parentheses.

2. Temperature and precipitation

In the NONSPH experiment, the global-mean 2-m air temperature is 1.17 K lower than in SPH, and the difference amounts to several K at high latitudes (**Fig. 2a**). Furthermore, the global-mean precipitation is reduced, and the ITCZ is shifted towards north (**Fig. 2b**). The ITCZ shift is consistent with a somewhat larger cooling in the southern hemisphere than in the northern hemisphere (but it could be exaggerated as the use of a mixed-layer ocean precludes changes in ocean heat transport). A **global-mean cooling of $\Delta T2$ = -1.17 K for a "radiative forcing" of ΔF = -0.218 W m^{-2} implies an extreme climate sensitivity parameter** of $\lambda = \Delta T2 / \Delta F$ =5.36 W m^{-2} K^{-1}. This is much larger than the corresponding sensitivity associated with doubling the atmospheric CO_2 concentration (for this model version, $\lambda \approx$ 0.86 W m^{-2} K^{-1}).

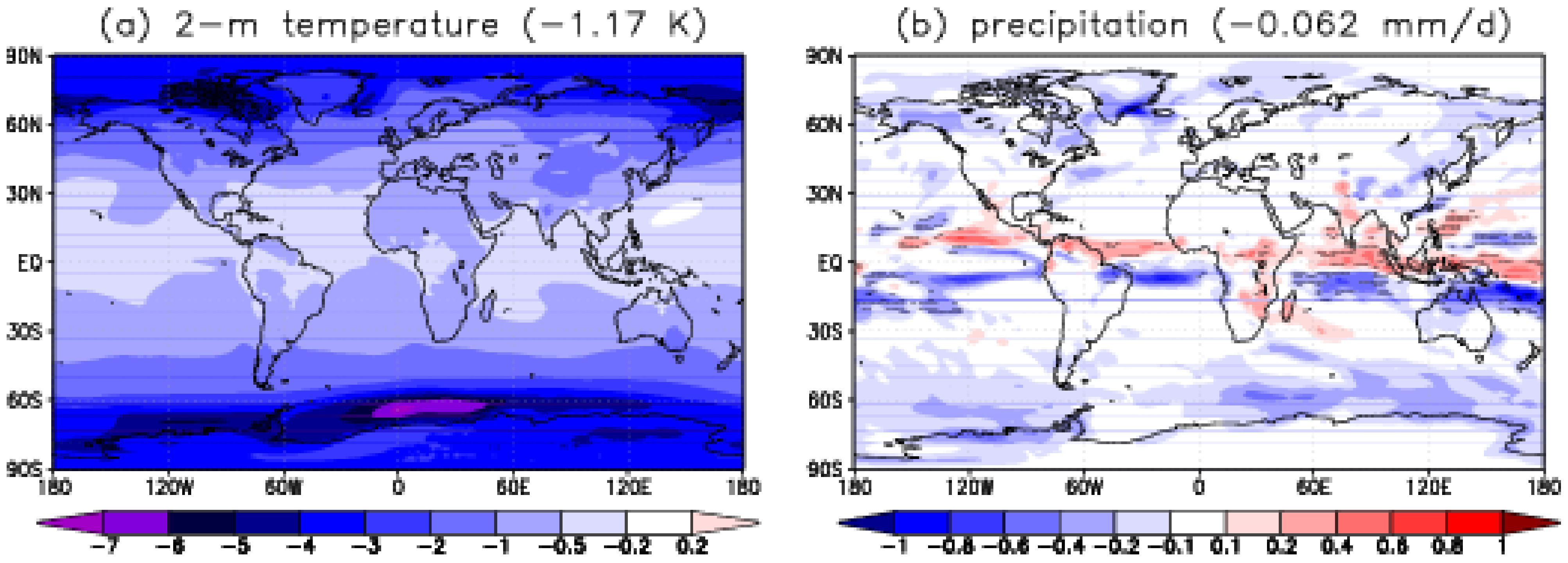

Fig. 2. Differences between the NONSPH and SPH experiments in **(a)** near-surface air temperature and **(b)** precipitation. Global mean values are given in parentheses.

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the NorESM model

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3. Snow and ice feedbacks

The large response to changed snow grain shape is related to **very strong snow and sea ice feedbacks**, that is, increased snow and sea ice cover in the NONSPH experiment (**Fig. 3a**). Consequently, the actual difference in surface albedo between the NONSPH and SPH experiments **(Fig. 3b)** is much larger than the difference derived from diagnostic radiation calculations (**Fig. 1a**); by over a factor of 6 in the global mean.

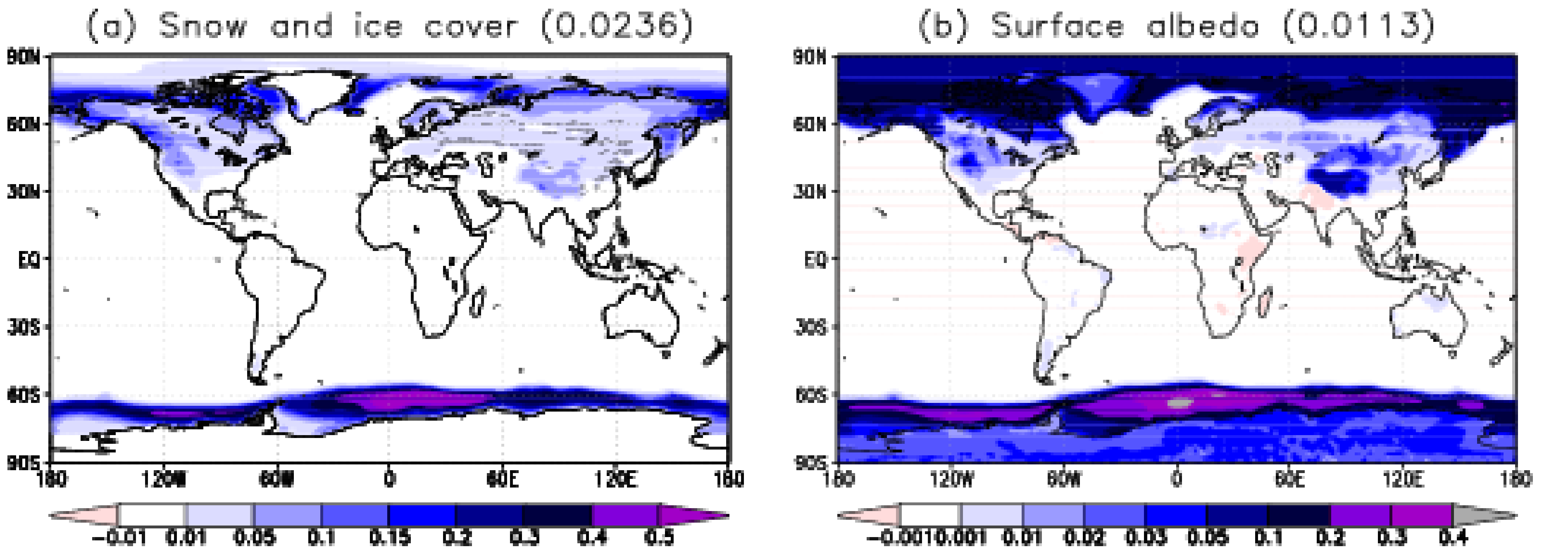

Fig. 3. Differences in annual-mean surface albedo between the NONSPH and SPH experiments in **(a)** snow and sea ice cover and **(b)** surface albedo.

4. Comparison with satellite albedo data

Figure 4 compares the surface albedo of Antarctica and Greenland in the SPH and NONSPH experiments and in three satellite datasets. The **large differences between different satellite datasets** preclude firm conclusions. Nevertheless, **NONSPH overestimates the albedo compared to the satellite datasets, except for CLARA-SAL over Antarctica**. In principle, a high bias in snow albedo could arise from biases in snow single-scattering properties (e.g., too low asymmetry parameter), from a low bias in effective snow grain size, or from other factors such as the neglect of snow surface structure in the radiation calculations.

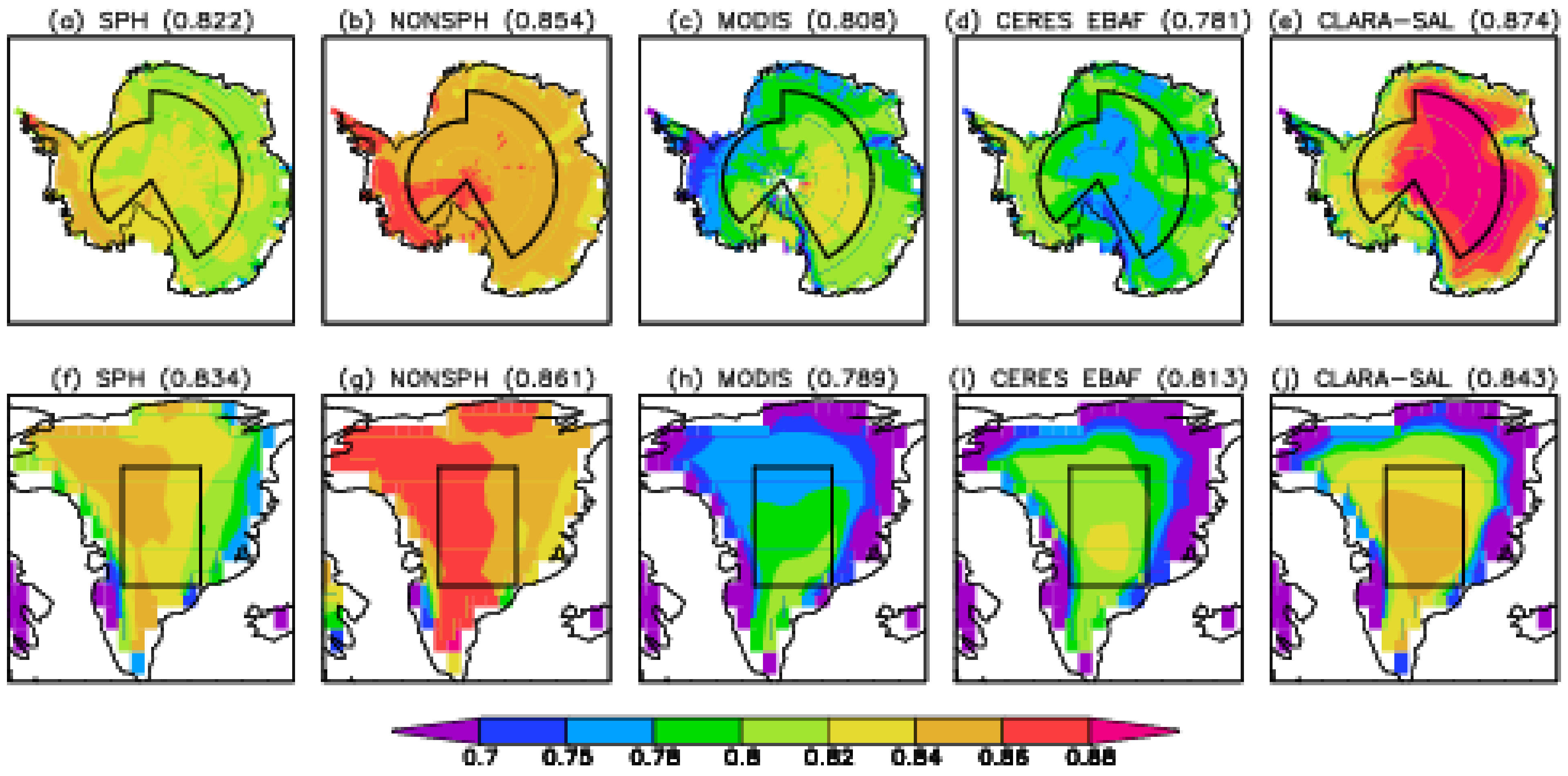

Fig. 4. Annual-mean surface albedo in Antarctica (upper row) and in Greenland (lower row) in the SPH and NONSPH experiments and in three satellite datasets: MODIS MCD43C3.005, CERES EBAF-Surface Ed2.8 and CLARA-SAL. The values in parentheses are averages over the two regions enclosed by the solid black lines.

5. A tuning exercise

The NONSPH experiment has a cold bias especially at high latitudes. A possible method of retuning the model (at least technically) is to increase the snow grain size, which lowers the snow albedo. **When the size of non-spherical snow grains is increased by ~70%, the simulated climate becomes almost statistically indistinguishable from that in the SPH experiment** (**Fig. 5**).

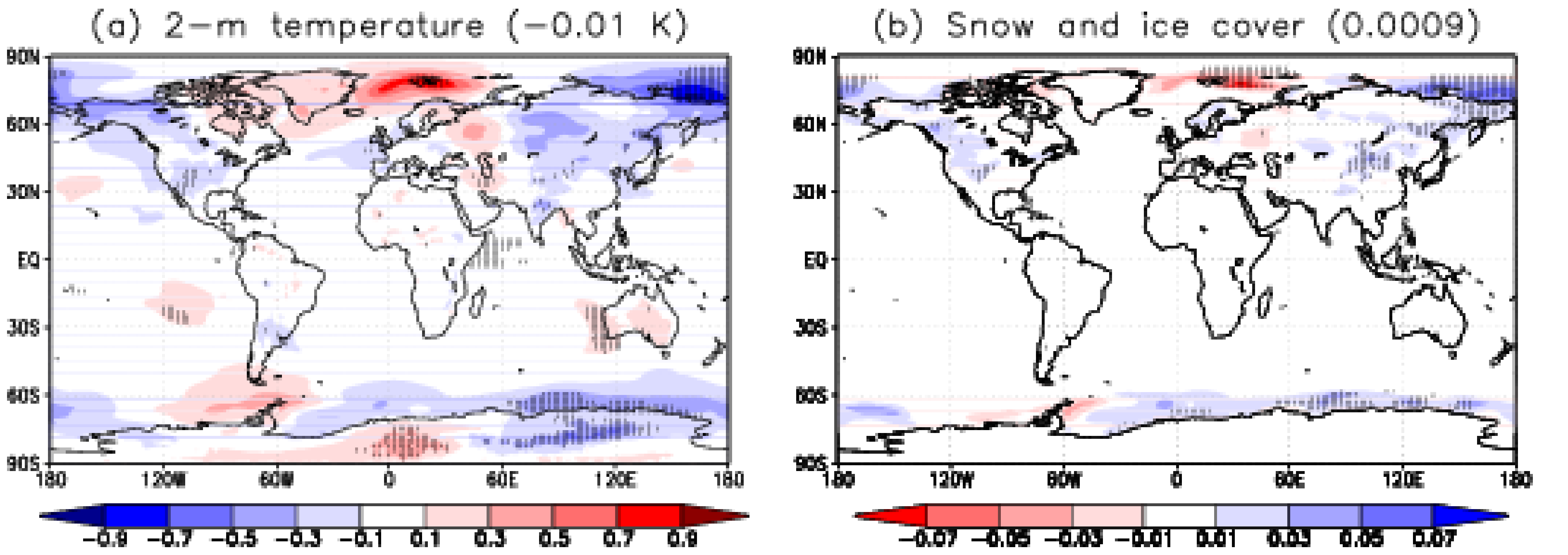

Fig. 5. Differences between experiments with non-spherical and spherical snow grains when in the former experiment, snow grain size is increased by ~70%, in **(a)** near-surface air temperature and **(b)** snow and sea ice cover.

6. Radiative effect of absorbing aerosols in snow

For fixed snowpack properties, the radiative effects (RE) of absorbing aerosols in snow are generally smaller when assuming non-spherical rather than spherical snow grains, especially for a thick snowpack. This is because solar radiation penetrates deeper in the snow in the case of spherical snow grains, allowing for a higher chance of aerosol absorption. Indeed, the RE is smaller for NONSPH than SPH in permanently snow-covered regions of Greenland and Antarctica **(Fig. 6**). However, **in many other regions and even in the global mean sense, the RE is larger in the NONSPH experiment**. The main reason for this is that in the colder climate of the NONSPH experiment, snow melts later in spring, exposing the snowpack to more solar radiation.

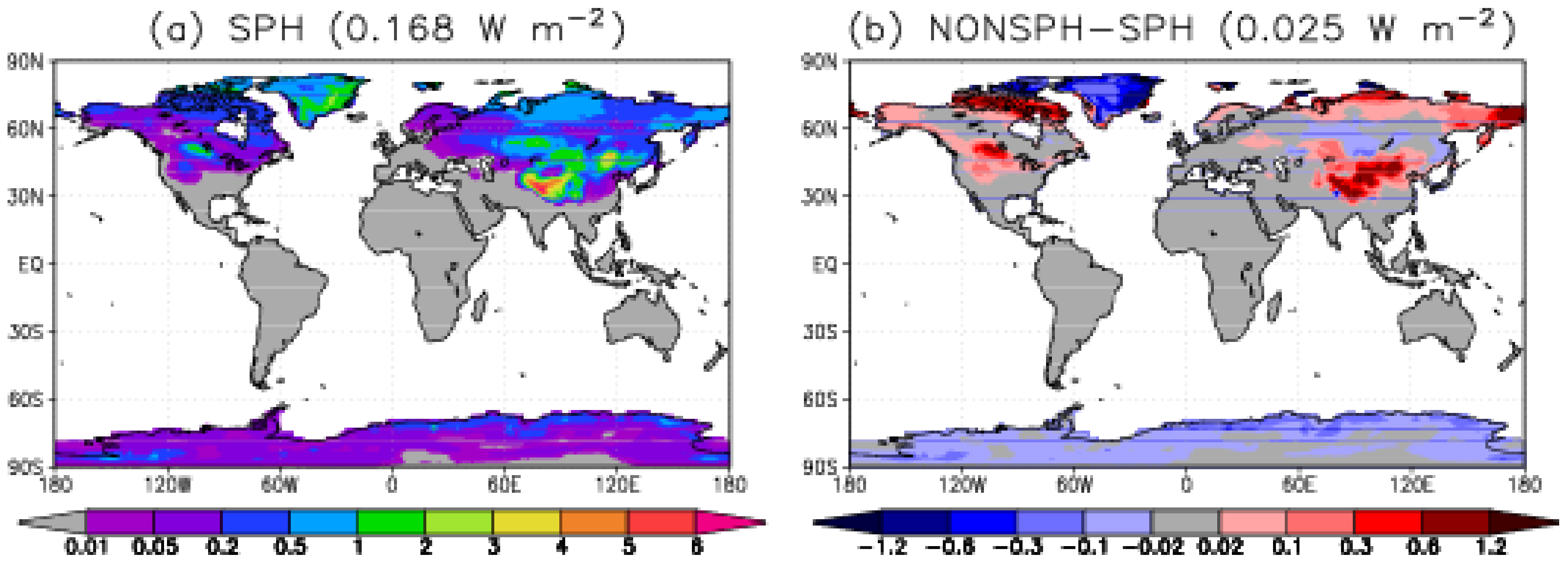

Fig. 6. **(a)** Annual-mean surface radiative effect of absorbing aerosols in snow (BC and mineral dust) in the SPH experiment and **(b**) the difference between NONSPH and SPH. Global land-area mean values are given in parentheses.