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Reducing Earth System Model High-Latitude Biases by Incorporating Observationally-Based Infrared Surface Emissivity

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Earth System Models (ESMs) have exhibited cold biases in Arctic Ocean wintertime surface air temperature for at least the last two CMIP exercises, with profound implications for their predictive capabilities for both the cryosphere and low latitudes. While the search for the root causes of these biases has considered the contributions of the representation of surface albedo and cloud effects, we explore how the incorporation of a realistic representation of infrared radiative transfer processes in ESMs can reduce wintertime Arctic surface temperature biases in CESM1.2.2 from -7.2 ± 0.9 K to $^{-1}.1 \pm 1.2$ K, relative to observations. Specifically, we explore how the incorporation into an ESM of physically-based infrared spectrally-resolved surface emissivity, which recognizes that frozen surfaces tend to be more emissive than unfrozen ones, helps rectify longstanding model biases in historical runs. At the same time, we find that the relative roles mid-infrared emissivity and far-infrared emissivity in affecting the surface and atmospheric radiative energy environment can vary substantially both with snow-grain, atmospheric water vapor, and condensates. However, there is insufficient information to characterize this variability, so we can only use realistic, instead of real, surface emissivity at present.

These findings suggest that observations including both the mid-infrared and far-infrared are necessary to determine the temporal and spatial variability of surface emissivity. However, there are approximately seven orders of magnitude more mid-infrared measurements than far-infrared remote sensing measurements. Nevertheless, the limited number of upwelling spectrally-resolved observations of both the mid- and far-infrared in Antarctica and Greenland suggest that spectral surface emissivity can be retrieved via remote sensing. Therefore, the comprehensive mid- and far-infrared observations that are proposed as part of the Far-infrared-Outgoing-Radiation Understanding and Monitoring (FORUM), a candidate ESA Earth Explorer – 9 mission, may help constrain this quantity for Earth System Models.