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Advection-radiation fog over the northeast Pacific in summer: long-term ship observations and LES simulations

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The fog over the northwest Pacific is predominantly advection fog, which forms due to the cooling of moist air by relatively cold sea surface. Using 40-year ship observations, we find that the fog air temperature (FAT) frequently ($\sim$30 % of the total fog observations) falls below sea surface temperature (SST) over the northwest Pacific, and the fog with positive SST-FAT mostly occurs during night when longwave radiative cooling is not canceled out by solar radiative heating at fog top. We subsequently perform large-eddy simulations (LESs) to study the physical processes within boundary layer producing the positive SST-FAT. The LESs follow the trajectory of an air parcel from the warm to cold ocean surface and are initialized with typical summertime boundary-layer soundings. The control run is forced by realistic solar incidence with diurnal variation. Results show that FAT falls below SST 3 hours after fog occurrence. Heat budget analysis of the fog/cloud-resident boundary layer suggests that the longwave radiative cooling at fog top overcomes the sea surface cooling 2 hours after fog formation. After that, the positive buoyancy flux produced by the longwave radiative cooling at fog top takes over the turbulent production from surface wind shear, and further thickens the fog layer. The turbulence intensified by the air-sea instability kills fog droplets and leads to the transition of fog to stratus. The FAT in the sensitive run with diurnal mean solar radiation keeps above SST, indicative of the important role of radiative budget within fog layer for the fog development, maintenance, and dissipation. This study advances our knowledge of advection fog by clarifying the important role of fog-top radiative cooling, and helps improve the skills in fog prediction over the northwest Pacific where marine traffic is heavy.