Modelling radiative processes in the nocturnal boundary layer

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The nocturnal boundary layer (NBL) that develops over land is important in weather forecasting, climate modeling and the dispersion of pollutants. Various physical processes including radiation and turbulence play a key role in the formation and evolution of the NBL. The exact role of each process and its interaction with others is, however, poorly understood especially under calm clear conditions. Modeling radiative transfer is very difficult due to (a) the non-local nature of the radiation field (b) the directional nature and heterogeneity of the photon trajectories and (c) the sensitive dependence of the absorption and emission processes on wavelength. Radiative parameterization involves an appropriate simplification of one or more of the aforementioned features, thereby providing a computationally efficient yet accurate method of calculating flux profiles within the atmosphere. For example, the average of the transmission over all zenith angles is routinely replaced by the transmission along an average path at a zenith angle \( \theta = \cos^{-1}(1/\beta) \) where \( \beta \) is the diffusivity factor (Goody, 1964).

At the coarsest level in frequency parameterization, computationally efficient broadband flux-emissivity schemes are often employed to model infrared radiative exchanges in the atmosphere. The central quantity in these schemes is the flux-emissivity - the emissivity of an isothermal column of the participating medium. Flux-emissivity schemes have mostly been used for cases where the bounding surfaces are radiatively black. Garratt and Brost (1981) extended the formulation to non-black surfaces using the surface emissivity to divide the up-welling flux into emission and reflection contributions, each of which is attenuated by the complement of the flux-emissivity. This extension is erroneous, however, and leads to a spurious near-surface cooling in the opaque bands (Mukund, et al., 2010; Ponnulakshmi et al., 2012a). The surface emissivity enters the formulation in a more subtle manner, and we present the correct formulation for non-black surfaces that eliminates the spurious cooling, and discuss in some detail earlier NBL calculations affected by this error. It is then argued that the error in varying amounts is, in fact, inherent in any frequency-parameterised radiative transfer model, involving non-black emitting surfaces, that does not fully resolve the emission spectrum of the participating medium. The basic emissivity scheme is then extended to allow for a non-isothermal atmosphere, multiple reflections between a pair of reflective surfaces (a configuration commonly employed in laboratory experiments), and an angular dependence of the radiant intensity; the final generalization avoids the use of a diffusivity factor, and enables one to account for directional characteristics of surface emission and reflection.

References